POTENTIAL SOLUTIONS FOR ACHIEVING THE SAN JOAQUIN RIVER DISSOLVED OXYGEN OBJECTIVES

PREPARED FOR:

DE CUIR & SOMACH
SACRAMENTO, CALIFORNIA
AND

DEPARTMENT OF MUNICIPAL UTILITIES
CITY OF STOCKTON, CALIFORNIA

PREPARED BY:

JONES & STOKES ASSOCIATES
SACRAMENTO, CALIFORNIA

JUNE 1998

D—041880

Potential Solutions for Achieving the San Joaquin River Dissolved Oxygen Objectives

Prepared for:

De Cuir & Somach
400 Capitol Mall, Suite 1900
Sacramento, CA 95814-4407
916/446-7979
Contact: Paul S. Simmons

and

City of Stockton
Department of Municipal Utilities
2500 Navy Drive
Stockton, CA 95206
209/937-8781
Contact: Donald M. Dodge

Prepared by:

Jones & Stokes Associates
2600 V Street, Suite 100
Sacramento, CA 95818-1914
916/737-3000
Contact: Russ Brown

June 1998

Jones & Stokes Associates, Inc. 1998. Potential solutions for achieving the San Joaquin River dissolved oxygen objectives. (JSA 97-180.) June. Sacramento, CA. Prepared for De Cuir & Somach, Sacramento, CA, and City of Stockton Department of Municipal Utilities, Stockton, CA.

TABLE OF CONTENTS

D-041883

Table of Contents

List of Tables

Table

D—041886

D-041886

List of Figures

Figure

D-041891

List of Acronyms and Abbreviations

$\mu g/l$	micrograms per liter
$\mu S/cm$	microsiemens per centimeter
AF	acre-feet
ammonia-N	ammonia-nitrogen
BOD	biochemical oxygen demand
cfs	cubic feet per second
City	City of Stockton
Corps	U.S. Army Corps of Engineers
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CVRWQCB	California Regional Water Quality Control Board, Central Valley Region
DFG	California Department of Fish and Game
DO	dissolved oxygen
DWR	California Department of Water Resources
EC	electrical conductivity
ft/sec	feet per second
ISDP	Interim South Delta Program
lbs/day	pounds per day
mg/l	milligrams per liter
m/sec	meters per second
msl	mean sea level
nitrate-N	nitrate-nitrogen
NPDES	National Pollutant Discharge Elimination System
RWCF	regional wastewater control facility
SOD	sediment oxygen demand
SWP	State Water Project
SWRCB	State Water Resources Control Board
TSS	total suspended solids
USGS	U.S. Geological Survey
UVM	ultrasonic velocity meter
VSS	volatile suspended solids
1995 WQCP	Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary

D-041893

EXECUTIVE SUMMARY

Executive Summary

INTRODUCTION

The purpose of this report is to help improve understanding of the processes that affect dissolved oxygen (DO) in the lower San Joaquin River and to identify potential management solutions for improving DO conditions in the Stockton Deepwater Ship Channel. The concentration of DO in this reach frequently declines below 5 milligrams per liter (mg/l), especially during the warm months. There is concern that such DO concentrations may negatively affect resident fish and other aquatic life and impede migration of chinook salmon. A recommendation related to immigration of chinook salmon prompted the State Water Resources Control Board (SWRCB) to impose a fall (September, October, and November) DO objective of 6 mg/l for the reach between Stockton and Turner Cut, in addition to the year-round DO objective of 5 mg/l established by the Central Valley Regional Water Quality Control Board (CVRWQCB) for all locations on the San Joaquin River. Developing a strategy for improving DO conditions in the river remains a pressing concern.

This report is based primarily on analyses of field data collected by the City of Stockton (City), the California Department of Water Resources (DWR), and other agencies between 1986 and 1995 and on output from the Stockton water quality model (Schanz and Chen 1993). The following sections describe the factors affecting DO concentration in the Deepwater Ship Channel and four management options that were assessed. The final descriptive section summarizes recommendations based on assessment of the field data and Stockton water quality model output.

FACTORS AFFECTING DISSOLVED OXYGEN CONCENTRATION

Saturation Concentration

An important reference point for any discussion of DO in aquatic ecosystems is the saturation concentration. The saturation concentration represents the maximum amount of oxygen that can be maintained in solution (i.e., dissolved) at a given temperature and atmospheric pressure. The saturation concentration is primarily a function of water temperature: as temperature increases, saturation concentration decreases. For example, at 9°C (48°F)—the monthly average water temperature of the San Joaquin River near Stockton during January—the saturation concentration is 12 mg/l, whereas at 25°C (77°F)—the average water temperature for August—the saturation concentration declines to 8.4 mg/l. This temperature dependence is one of the reasons that DO concentrations generally are lowest during summer and early fall.

Processes Supplying and Removing Oxygen

The amount of oxygen dissolved in water at any given time represents a balance between processes that supply oxygen to the water and those that remove it from the water.

The two main processes supplying oxygen to the Deepwater Ship Channel are reaeration and photosynthesis. Reaeration is a physical process that transfers oxygen from the atmosphere to the water column whenever DO concentration in the water is less than the saturation concentration. Photosynthesis is a light-dependent, biological process performed by algae (microscopic plants) suspended in the water.

Two major processes that remove oxygen involve decomposition of dissolved and particulate organic matter (i.e., biochemical oxygen demand [BOD]) and nitrification (oxidation) of dissolved ammonia. These decomposition and oxidation processes occur within the water column and at the sediment-water interface (i.e., sediment oxygen demand [SOD]) and are performed by a number of highly specialized bacteria having metabolic rates that are a function of water temperature: as temperature increases, metabolic rates increase. These processes are illustrated in Figure ES-1. It is not possible to identify the relative importance of these processes with field measurements alone; a water quality model is needed to determine the cumulative contribution of these processes to the overall DO balance.

Conditions Affecting Oxygen Supply and Removal in the Stockton Deepwater Ship Channel

The natural reaeration rate (the amount of oxygen that is transferred from the atmosphere to the water per unit time) in the Deepwater Ship Channel is slow because the channel is deep (mean depth is 22 feet) and has relatively slow tidal velocities. Also, the great depth, high turbidity, and steep side slopes of the Ship Channel combine to make it a poor place for aquatic plant production. Only a narrow band of water near the surface receives enough light to support suspended algal photosynthesis.

By contrast, between Mossdale and Vernalis and farther upstream, conditions for riverine algal production are generally good. Channel depth averages less than 3 feet, nutrients are generally available in surplus, and the travel time of the water is long enough for extremely high levels of algal biomass to develop by the time the water reaches Vernalis or Mossdale.

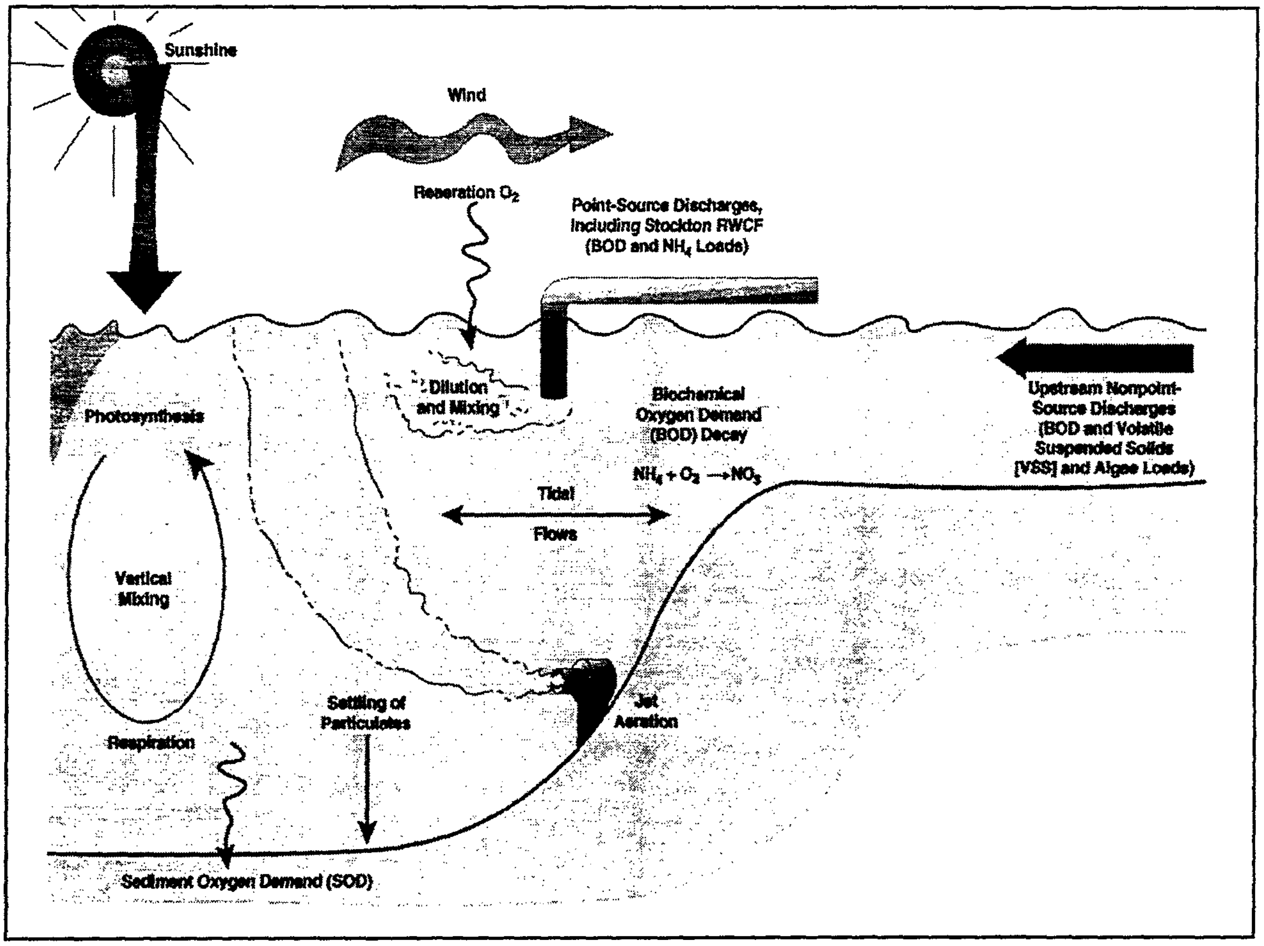


Figure ES-1. Factors Affecting Dissolved Oxygen Concentrations in the San Joaquin River

During periods of high algal production upstream, DO concentration at Mossdale (as recorded by continuous monitoring devices maintained by DWR) is frequently supersaturated because algal photosynthesis supplies oxygen to the water faster than it can be transferred across the air-water interface back into the atmosphere. This condition is only temporary, however. Routine monitoring at various locations downstream of Mossdale indicate that DO concentrations decline as the water flows toward the Deepwater Ship Channel. In fact, periods of supersaturation at Mossdale have been accompanied within a few days or weeks by extremely low levels of DO near Stockton (Figure ES-2).

The apparent linkage between high algal abundance at Mossdale and low DO concentrations near Stockton has long been appreciated (McCarty 1969). Algae that are adapted to shallow riverine conditions (i.e., conditions in which algae are continually circulating and have adequate light for photosynthesis) are transported into the Deepwater Ship Channel, where circulation is comparatively weak and light is virtually absent throughout most of the water column and on the riverbed. Under these conditions, most of the algae (more than 80% of chlorophyll) swept into the Ship Channel from upstream settle out of the euphotic (i.e., lighted) zone and begin to decompose and consume DO from the water column (BOD) or on the channel bottom (SOD).

Oxidation of organic matter (BOD) and nitrification of dissolved ammonia discharged from the City's oxidation ponds also affect DO in the Deepwater Ship Channel. It is not known precisely how much of the actual DO consumption in the Ship Channel results from decomposition of incoming algal biomass and how much results from oxidation of effluent organic matter and ammonia. However, the extremely high levels of algal productivity characterizing the San Joaquin River upstream of Mossdale during the warm months play an important role in affecting DO concentrations downstream.

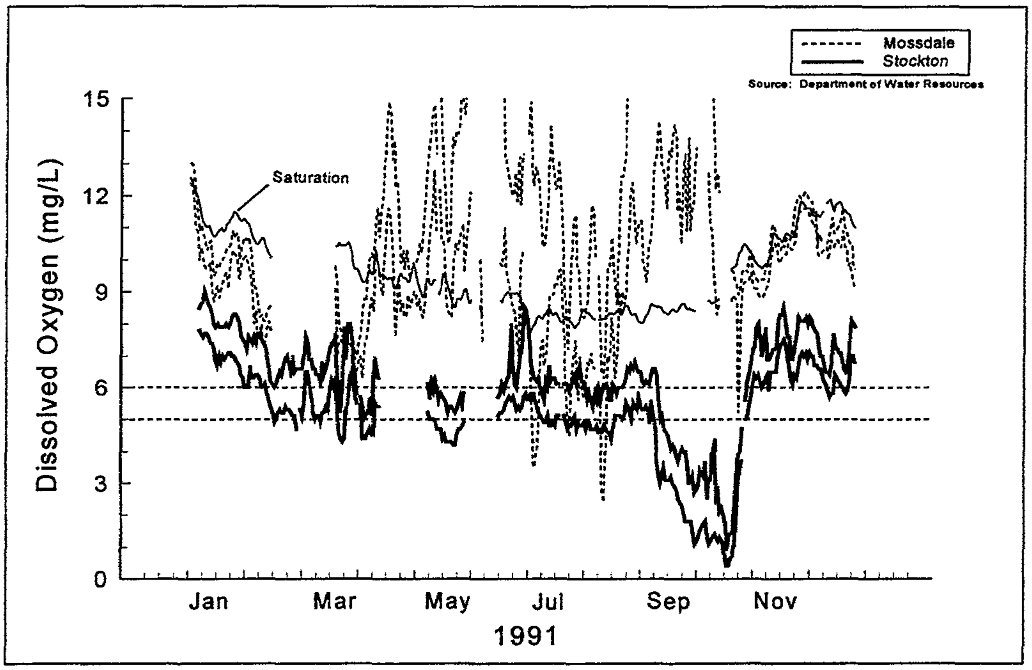


Figure ES-2. Minimum and Maximum Dissolved Oxygen Concentrations in the San Joaquin River at Mossdale and in the Stockton Deepwater Ship Channel

MANAGEMENT OPTIONS FOR CONTROLLING DISSOLVED OXYGEN CONCENTRATION

Strategies for improving (i.e., increasing) DO concentration in the Deepwater Ship Channel must center around practical ways to enhance processes that supply oxygen to the water or to slow down processes that consume oxygen. The Stockton water quality model was developed specifically to accurately evaluate these processes and their net effect on DO concentration. The Stockton water quality model thus provides a useful tool for evaluating and comparing the effectiveness of various management options.

This report describes results from the Stockton water quality model and use of those results to evaluate four strategies for improving DO conditions in the Deepwater Ship Channel: (1) controlling net flow at Stockton by installing an operable flow barrier (gate) at the head of Old River; (2) enhancing oxygen supply by installing artificial aeration devices in the Deepwater Ship Channel; (3) reducing SOD by reducing the influx of algal biomass from Mossdale; and (4) reducing oxygen demand from the City's regional wastewater control facility (RWCF) discharge. Each evaluation includes a summary description of the strategy and a discussion of how it could be implemented, what difficulties might be encountered, and how effective it would be in improving DO conditions in the Deepwater Ship Channel. Results of these evaluations are summarized below.

Comparisons of simulated and measured DO concentrations indicate that the Stockton water quality model accurately simulates many of the observed DO concentration patterns and is adequate for comparative investigations of management alternatives to improve DO concentrations and satisfy the regulatory DO criteria applicable in the San Joaquin River between Stockton and Turner Cut.

Control Flow at Stockton with an Operable Barrier at the Head of Old River

The Old River channel splits off from the San Joaquin River upstream of Stockton near Mossdale. Because a large fraction of the San Joaquin River flow measured at Vernalis is conveyed down the Old River channel, net flow near Stockton is much less than at Vernalis. Installing an operable barrier at the head of Old River would cause most of the flow at Vernalis to bypass the Old River channel diversion and continue past Stockton.

Increasing net flow through the Deepwater Ship Channel would increase the assimilative capacity of the San Joaquin River and would reduce travel time and associated effects of SOD and settling of organic particulates (i.e., river load). The Stockton water quality model results suggest that increasing net flow at Stockton would provide improvement in DO concentrations near Stockton throughout the year. Simulations comparing the DO concentrations at a net flow of 0 cubic feet per second (cfs) with the DO concentrations at a net flow of 1,000 cfs (assuming 1996 RWCF discharge loads) indicated that substantial DO increases could be expected during most months at the higher flow. Figure ES-3 shows the monthly average simulated DO concentrations at Station 3 (east end of Rough and Ready Island) and Station 5 (west end of Rough and Ready Island) with constant flows of 0 cfs and 1,000 cfs. Simulated DO concentrations were generally above the 5-mg/l objective when net flow at Stockton was 1,000 cfs. At 1,000 cfs, the 6-mg/l standard for the fall months was attained during October and November and most of September. The simulations indicate that managing flow at the head of Old River would provide a practical and effective method for controlling DO concentrations in the Deepwater Ship Channel. Figure ES-4 shows the average simulated DO concentrations for September with net flows of 0 cfs and 1,000 cfs. Both simulations assume 1996 RWCF discharge loads. Increasing the flow produces substantial changes in the

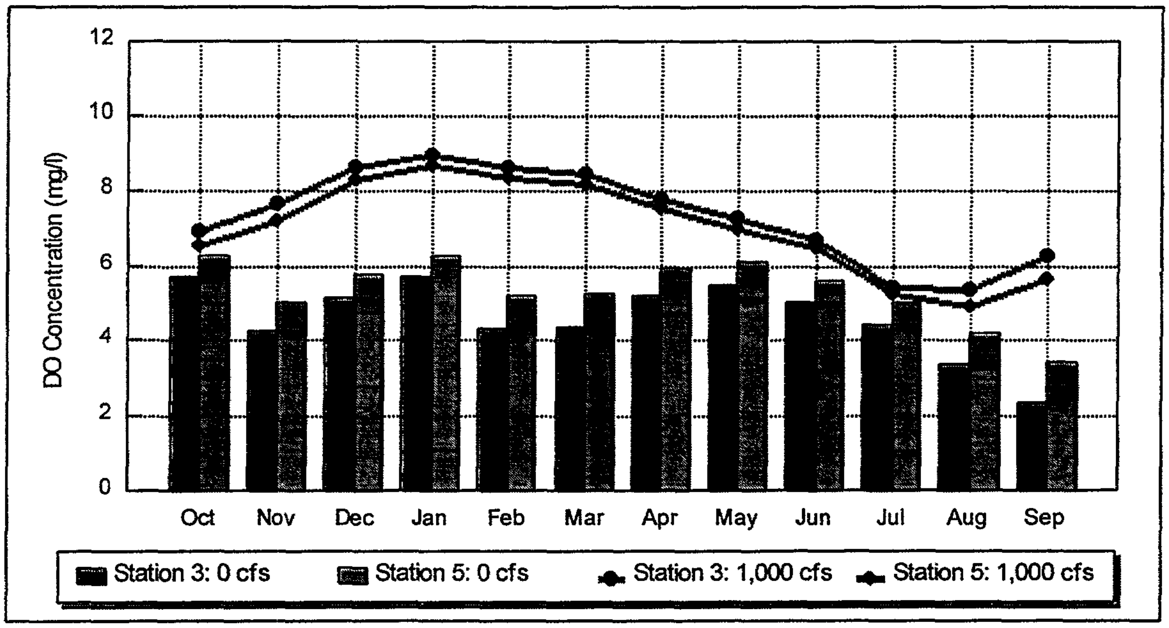


Figure ES-3. Average Simulated San Joaquin River Dissolved Oxygen Concentrations at Stations 3 and 5 Assuming 1996 RWCF Loads with Net Flows of 0 cfs and 1,000 cfs

average simulated DO concentrations between Station 1 (upstream of the RWCF discharge) and Station 5.

This strategy would be less effective, however, if the increased flow brought with it high amounts of algal biomass produced upstream of Mossdale. Thus, under some circumstances, leaving the operable gate open and allowing much of the organic load to proceed down the Old River channel might produce better DO conditions in the Deepwater Ship Channel. This observation points out the potential benefits of real-time barrier operations.

Install Aeration Device in the Stockton Deepwater Ship Channel

Natural reaeration in the Deepwater Ship Channel is a relatively slow process that depends on the DO deficit of the water (i.e., saturation concentration minus actual DO concentration), the depth of the channel, flow velocity, and wind speed. The average depth of the Deepwater Ship Channel is over 20 feet and, although the tidal flows average 2,000 cfs, the average velocity is only about 0.1 foot per second. Natural reaeration increases with the DO deficit. At a given DO deficit, reaeration decreases with channel depth and increases with flow velocity and wind speed. Adding oxygen to the water with aeration devices is one option for increasing DO concentration in the Deepwater Ship Channel during periods when the DO deficit is high. This is a strategy that has been employed in other parts of the country.

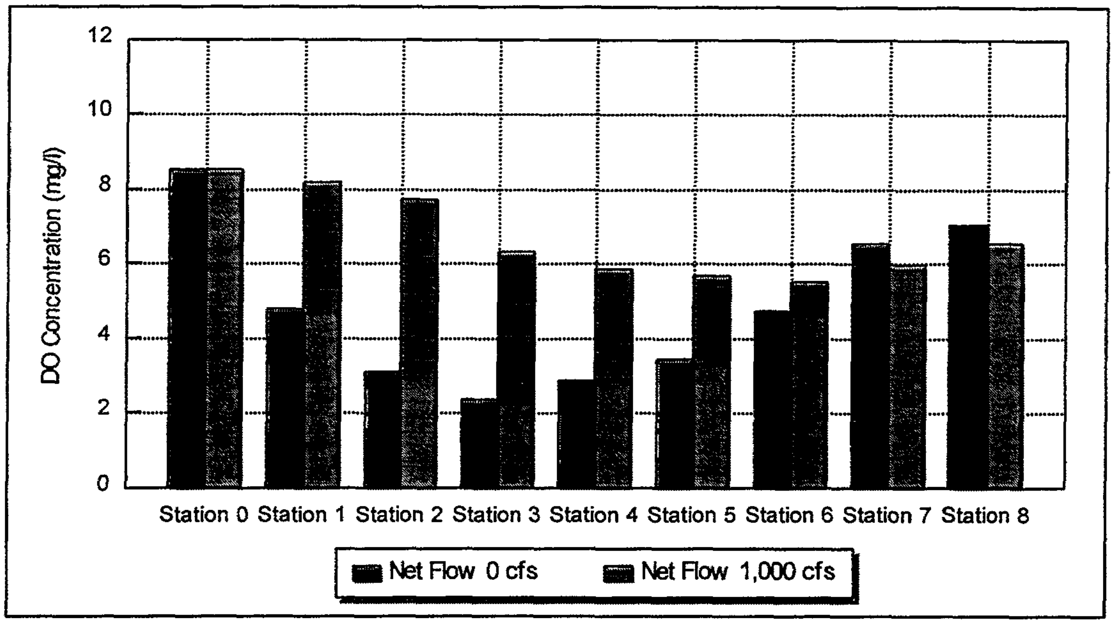


Figure ES-4. Average Simulated San Joaquin River Dissolved Oxygen Concentrations in September Assuming 1996 RWCF Loads with Net Flows of 0 cfs and 1,000 cfs

Increased reaeration can be achieved using in-stream bubble jet/diffuser systems or side-stream waterfall systems. The U.S. Army Corps of Engineers (Corps) has operated a bubble jet system in the Deepwater Ship Channel since fall 1993. The device is designed to deliver 2,000 pounds per day of oxygen to compensate for a 0.2-mg/l reduction in DO estimated to have resulted from a channel deepening project completed by the Corps. No field studies, however, have been completed to determine the actual performance of the aeration system in the Deepwater Ship Channel.

A side-stream aeration system would involve pumping water low in DO from the Ship Channel and routing it through a series of waterfalls back to the Ship Channel. Such systems can be designed to resemble natural streams and thus become the central feature of parklike settings for recreational activities (i.e., Chicago). The average DO deficit reduction is proportional to the fraction of the flow aerated to saturation; to increase the Deepwater Ship Channel DO concentration from 5 mg/l to 6 mg/l in September (reducing the deficit by 25% from 4 mg/l to 3 mg/l) with a flow of 1,000 cfs would require pumping 25% (250 cfs) of the channel flow through the aerator system.

The Stockton water quality model results suggest that artificial aeration could be a viable method of meeting the DO objectives for the Deepwater Ship Channel. According to the model, adding 4,500 pounds per day of oxygen to the Ship Channel at Station 3 would result in a 0.5-mg/l increase in DO at a net flow of 1,000 cfs. This improvement would be sufficient to achieve the 5-mg/l objective in August and the 6-mg/l objective during most of September at all the stations.

Figure ES-5 shows the average simulated DO concentrations for September at a net flow of 1,000 cfs with 4,500 pounds per day of aeration compared with simulated DO concentrations at 1,000 cfs but without the aeration. Both simulations assume 1996 RWCF discharge loads. The City is presently conducting more detailed studies of the feasibility and benefits associated with river aeration facilities.

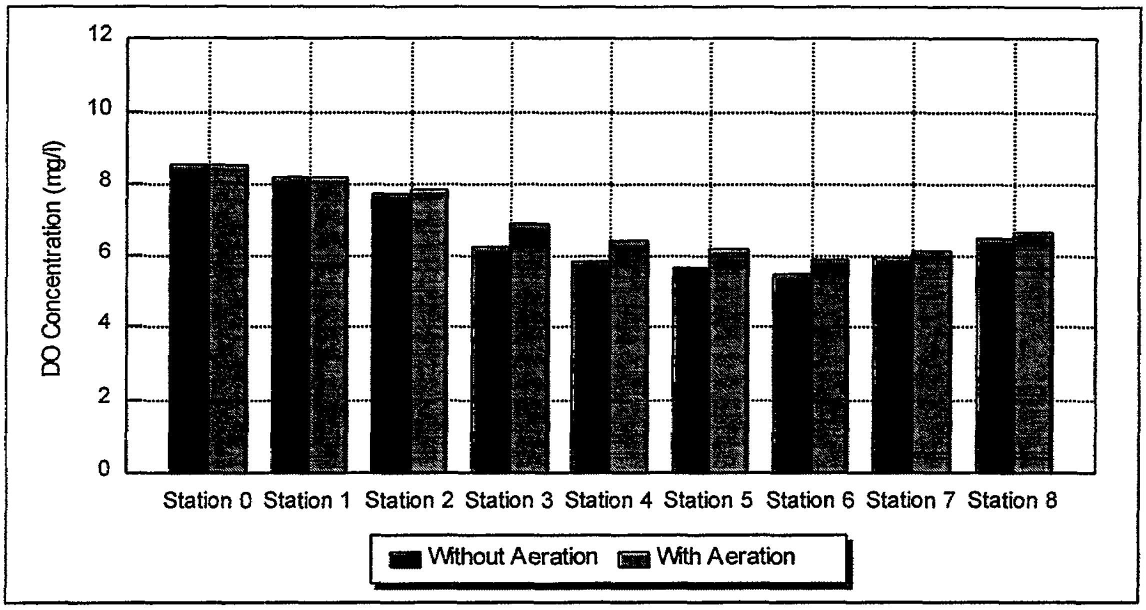


Figure ES-5. Average Simulated San Joaquin River Dissolved Oxygen Concentrations in September Assuming 1996 RWCF Loads and 1,000 cfs Flow with and without 4,500-lb/day Aeration

Reduce Influx of Algal Biomass from Mossdale

Exceptionally high levels of algal biomass prevail at Mossdale. Reducing algal biomass levels during warm summer months would reduce the loading of organic material (i.e., volatile suspended solids [VSS]) that produce BOD and SOD in the Deepwater Ship Channel, thereby leading to higher DO concentrations. To reduce algal biomass at Mossdale would require reducing nutrients in the San Joaquin River channel upstream of Mossdale.

Reducing nutrient concentrations in the river can be achieved by reducing these constituents in the agricultural drainage discharges to the San Joaquin River (i.e., total maximum daily load [TMDL] approach). Defining these load reduction goals should include establishing a monitoring network that measures nitrogen and phosphorus concentrations. A monitoring network intended for managing salt loads in the San Joaquin River is already in place and could be modified to include nutrient monitoring.

Once nutrient reduction goals were developed for the major nutrient sources, an effort to ensure the use of agricultural best management practices (BMPs) for the protection of water quality should be implemented in cooperation with landowners, the CVRWQCB, local watershed districts, nongovernmental organizations, and other interested parties. This should be a long-term strategy for improving general water quality and DO conditions in the Deepwater Ship Channel.

Another option for reducing the influx of algal biomass into the Deepwater Ship Channel from Mossdale would involve manipulating channel hydraulics with an operable gate at the head of Old River. One or more upstream stations presently equipped for continuous monitoring of temperature and conductivity could be upgraded to include continuous measurement of *in vivo* fluorescence as an estimate of chlorophyll concentration (algal biomass). When biomass is high, the gate could be opened and the biomass load would be diverted toward the export pumps. When the continuous monitors indicated that the levels of algal biomass at Mossdale were relatively low, the gate could be closed to allow the water with lower algae levels into the Deepwater Ship Channel. Such a real-time management system would need to be coordinated with other objectives designed to manage water levels, salt concentration, and fish habitat quality.

**Reduce Load from the City of Stockton
Regional Wastewater Control Facility**

The ammonia and organic matter discharged from the City's oxidation ponds stimulate microbial processes that consume oxygen in the Deepwater Ship Channel. This DO demand could be reduced if the RWCF discharge were eliminated or if the effluent's ammonia concentration were reduced. The most reliable method for ammonia removal would require adding expensive nitrification systems to the RWCF.

The Stockton water quality model simulations indicate that even the complete elimination of the RWCF discharge (i.e., simulated to show the maximum possible DO improvement) would not result in achievement of the fall DO objective of 6 mg/l in September unless the river flow is increased substantially. Figure ES-6 shows the average simulated DO concentrations for September with a net flow of 1,000 cfs and with the RWCF effluent completely eliminated. The simulated effects of eliminating the RWCF discharge on DO concentrations are greatest at low flows and decrease as river flow increases. The total effect of the assumed 1996 RWCF loads at a flow of 1,000 cfs is less than 1 mg/l in September. Figure ES-7 shows that the effects of eliminating RWCF discharge loads with a net flow of 1,000 cfs are less than 1 mg/l in all months.

Increasing flows at Stockton through operation of a barrier at the head of Old River would be more cost effective and feasible than attempting to eliminate the wastewater discharge. Using aeration devices would likely be a more cost-effective way to increase DO concentration than using ammonia-reduction facilities. Consequently, the most promising alternatives for achieving the 6-mg/l objective are managing flow, using reaeration devices, and controlling upstream nonpoint sources of nutrients and organic loading.

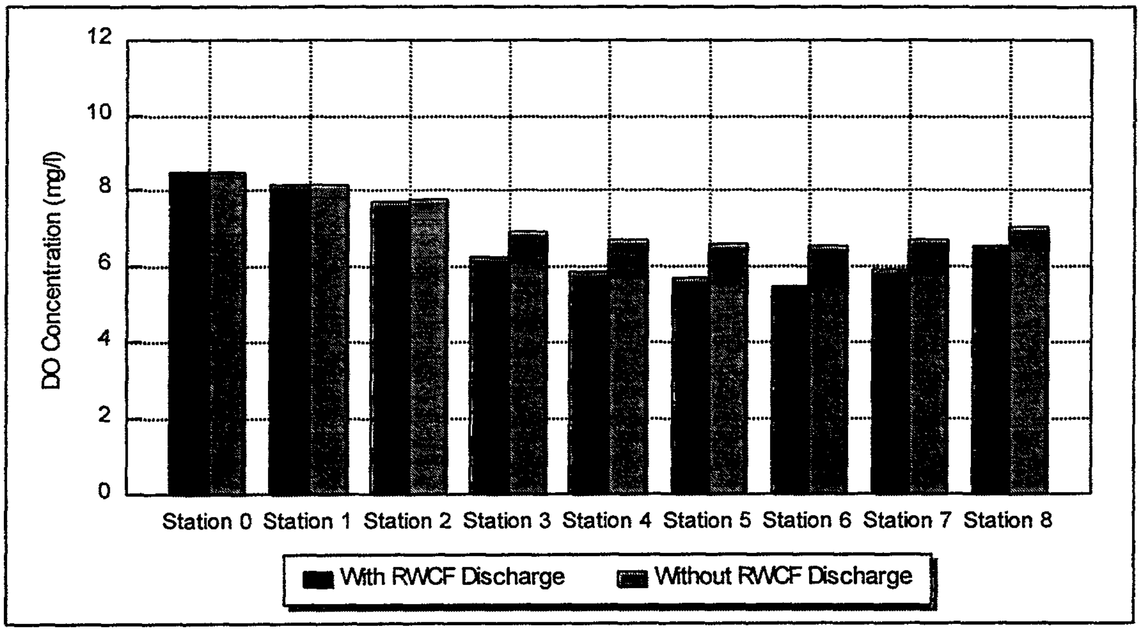


Figure ES-6. Average Simulated San Joaquin River Dissolved Oxygen Concentrations in September with Net Flow of 1,000 cfs with RWCF Discharge (1996 Loads) and without RWCF Discharge

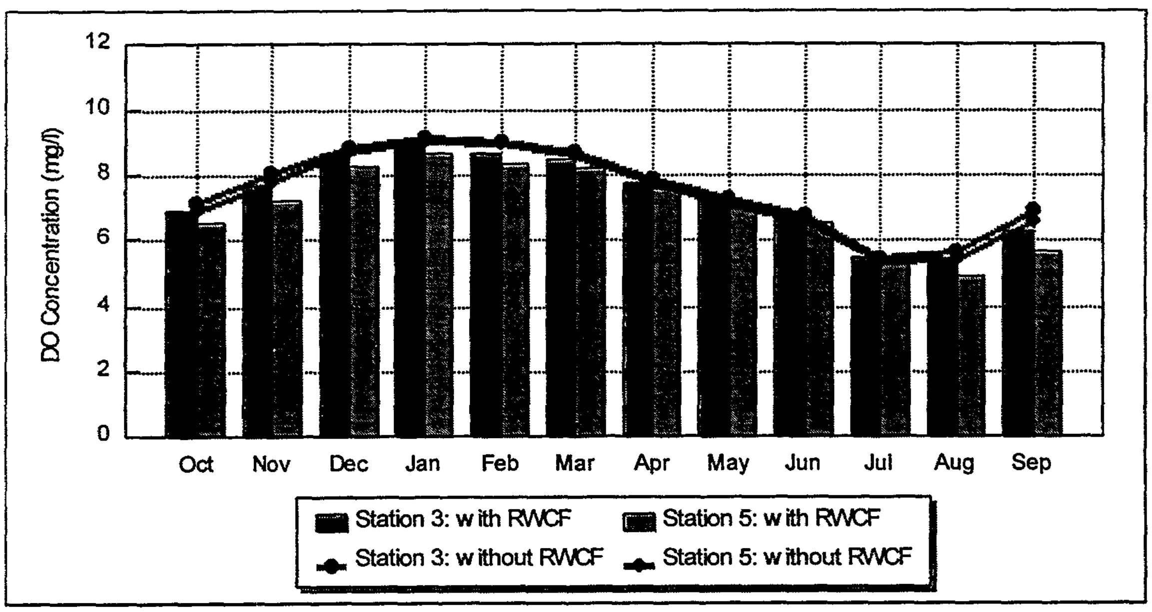


Figure ES-7. Average Simulated San Joaquin River Dissolved Oxygen Concentrations at Stations 3 and 5 with Net Flow of 1,000 cfs with RWCF Discharge (1996 Loads) and without RWCF Discharge

MAJOR FINDINGS AND RECOMMENDATIONS

Comparative analysis of historical BOD loads discharged from the RWCF and algal concentrations at Mossdale indicates that algal production upstream in the San Joaquin River (in combination with the DO saturation concentration, channel configuration, and flows) is a major reason for depressed DO concentrations downstream in the Stockton Deepwater Ship Channel. This finding is supported by Stockton water quality model simulations indicating that even complete elimination of the City's discharge would not allow routine attainment of the 6-mg/l DO objective under low-flow conditions. Further, the lack of significant river flow near Stockton is a major limitation on the ability to achieve the DO objectives. These results indicate that substantial improvement of DO conditions in the Ship Channel would require control of upstream loading of algal biomass and increased flow past Stockton.

The most effective way to reduce algal biomass loading from upstream and improve San Joaquin River water quality would be to install and adaptively operate a permanent tidal gate at the head of Old River. In conjunction with a real-time monitoring network designed to track flow, temperature, DO, chlorophyll concentration, and nutrient levels, as well as an aggressive program for reducing watershed-based nutrient load, the gate could be operated to both increase flow past Stockton and minimize the influx of BOD derived from algal production upstream.

This strategy would provide a comprehensive watershed approach (i.e., TMDL) to managing upstream processes responsible for low DO concentrations in the Deepwater Ship Channel and incorporate appropriate wastewater effluent limits. The flow management and aeration devices would be operated in response to measured DO concentrations and inflowing algae concentrations. This strategy would combine adaptive management techniques with appropriate regulatory controls to protect beneficial uses of water in the lower San Joaquin River. A more specific understanding of the aquatic resources affected by DO levels and the times at which these are present would be important to ensure that regulatory efforts are properly focused.

CITATIONS

McCarty, P. L. 1969. An evaluation of algal decomposition in the San Joaquin estuary. Prepared for the Federal Water Pollution Control Administration under Research Grant DI-16010 DLJ. Civil Engineering Department, Stanford University. Stanford, California.

Schanz, R., and C. Chen. 1993. City of Stockton water quality model volume I: model development and calibration. Philip Williams and Associates and Systech Engineering. Prepared for the City of Stockton, Stockton, CA.

REPORT TEXT

D-041907

D-041907

Potential Solutions for Achieving the San Joaquin River Dissolved Oxygen Objectives

INTRODUCTION

This report describes several alternatives for meeting the dissolved oxygen (DO) objectives for the San Joaquin River between Stockton and Turner Cut, as specified in the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (1995 WQCP) (California State Water Resources Control Board 1995) and the Water Quality Control Plan, Central Valley Region, Third Edition, for the Sacramento River Basin and the San Joaquin River Basin (Basin Plan) (California Regional Water Quality Control Board, Central Valley Region 1995). The report describes and evaluates the effects of all major oxygen-producing and oxygen-consuming processes that influence DO concentrations in this portion of the San Joaquin River. Management options include (1) controlling upstream contributions of nutrients and corresponding algal growth that produce a large inflowing organic load to the deeper portion of the San Joaquin River (i.e., Stockton Deepwater Ship Channel); (2) increasing DO concentrations by increasing flows in the San Joaquin River near Stockton with an operable barrier at the head of Old River; (3) using instream aeration devices; and (4) imposing more restrictive discharge limits for the Stockton regional wastewater control facility (RWCF). The available field data for this portion of the San Joaquin River are described and analyzed as the most accurate information related to the historical and existing water quality conditions near Stockton. The water quality of the San Joaquin River is assessed generally from a watershed viewpoint.

DO concentrations in the San Joaquin River are controlled by several processes that supply DO to the water or remove DO from the water. The two main processes supplying oxygen to the San Joaquin River are reaeration and photosynthesis. Reaeration is a physical process that transfers oxygen from the atmosphere to the water column whenever DO concentration in the water is less than the saturation concentration. Photosynthesis is a light-dependent, biological process performed by algae (microscopic plants) suspended in the water or aquatic plants (i.e., water hyacinth) growing in the water. The main processes that remove oxygen involve decomposition of dissolved and particulate organic matter (i.e., algal biomass) and nitrification (oxidation) of dissolved ammonia. These decomposition and oxidation processes occur within the water column and at the sediment-water interface and are performed by a number of highly specialized bacteria having metabolic rates that are largely a function of water temperature: as temperature increases, metabolic rates increase.

The San Joaquin River inflow and tidal flows near Stockton are very important factors in the processes controlling DO concentrations in the San Joaquin River between Stockton and Turner Cut. This report reviews flow management at Vernalis that is included in the 1995 WQCP and tidal and net flow measurements at Stockton that have been made during 1996 at the U.S. Geological Survey (USGS) ultrasonic velocity meter (UVM) station. The report describes existing flow conditions and the effects of several important factors controlling DO concentrations in this part of the San Joaquin River. Finally, the report evaluates the simulated effects of managing flows and other factors controlling DO concentrations with results of the Stockton water quality model developed by the City of Stockton (City) for planning and water quality assessment purposes.

The Stockton water quality model was developed for the City in 1993 (Schanz and Chen 1993) to support the evaluation of water quality conditions in the San Joaquin River between the head of Old River and Columbia Cut as part of the City's renewal of the Stockton RWCF National Pollutant Discharge Elimination System (NPDES) permit from the California Regional Water Quality Control Board, Central Valley Region (CVRWQCB). The model represents the San Joaquin River channel as about 25 segments that are each approximately 1 mile long. The model includes hydrodynamic (tidal) flow calculations and estimates the water transport, sources, and sinks (i.e., mass balance) for several water quality variables, including temperature, DO, biochemical oxygen demand (BOD), ammonia, nitrate, phosphorus, and algae biomass.

OBJECTIVES FOR DISSOLVED OXYGEN CONCENTRATION IN THE SAN JOAQUIN RIVER

The Basin Plan includes a general objective for DO concentration of 5 milligrams per liter (mg/l) at all locations throughout the year. Additionally, a 6-mg/l DO objective was originally adopted in the State Water Resources Control Board (SWRCB) 1991 Bay-Delta salinity control plan and was incorporated into the 1995 WQCP. This 6-mg/l objective applies from September 1 through November 30 in the San Joaquin River between Stockton and Turner Cut (Figure 1). This report discusses and compares alternatives for achieving both DO objectives. Data underlying the development of both of these objectives appear to be lacking.

A comparison of temperature and DO data with migration data indicated that adult chinook salmon (fall run) may migrate as early as September if water temperatures are less than 68°F (20°C) (Lifton 1990). However, water temperatures are normally higher than 20°C until late September, so most adult migration past Stockton is likely to occur in October and November. Studies performed by California Department of Fish and Game (DFG) in the 1960s indicated that DO concentrations of less than 5 mg/l apparently inhibited upstream migration (Hallock 1970). Protection of the entire migration season would be achieved with the general DO objective of 5 mg/l. However, as discussed below, the September-November 6-mg/l DO objective will be difficult to achieve when the water temperature is above 68°F because the DO saturation concentration will be only about 9 mg/l. Thus, for example, a conditional 6-mg/l DO objective applicable only when water temperature is less than 68°F would both protect migrating chinook salmon and would be a more reasonable standard to achieve. The habitat conditions that affect salmon migration and other aquatic resources include temperature, DO, and other water quality parameters in combination.

SAN JOAQUIN RIVER FLOWS

The San Joaquin River inflow and fluctuating tidal flows near Stockton are very important factors controlling DO concentrations in the San Joaquin River between Stockton and Turner Cut (Deepwater Ship Channel). These flow effects are described in this section.

Historical San Joaquin River Flows at Vernalis

Review of historical flow data for the San Joaquin River at Vernalis for 1972-1992 indicates that Vernalis flows have been greater than 1,000 cubic feet per second (cfs) about 80% or 90% of the time in every month. The historical monthly average San Joaquin River flows at Vernalis for 1972-1992 are summarized in Figure 2 as cumulative percentile or exceedence flows (i.e., cumulative percentile is equal to 100% - exceedence percentage). As shown in Figure 2, for example, the 80% exceedence flow (cumulative percentile of 20) for September was 1,067 cfs, which means that flows have been 1,067 cfs or greater 80% of the time in September. The median flow (50% exceedence) has been greater than 1,500 cfs for most months. For example, the September median flow was 1,597 cfs. The months with the lowest flows are generally July, August, and September.

Because of the large reservoir storage capacity in the San Joaquin River basin, flows at Vernalis during summer and fall are relatively constant, and there is no direct correlation of Vernalis flows with the total runoff index for the year (i.e., water-year classification). This suggests that the effects of flow on DO concentration near Stockton should be evaluated for a range of flows, independent of the runoff water-year classification.

Requirements for San Joaquin River Flows at Vernalis under the 1995 WQCP

The 1995 WQCP includes specified Vernalis flow objectives for February through June that depend on the San Joaquin River water supply index and are increased when the required X2 location is downstream of Chipps Island (see Table 3 of the 1995 WQCP). For example, the February-June flow requirements are 710 cfs (if X2 is upstream) or 1,140 cfs (if X2 is downstream) in critical dry years and 2,130 cfs or 3,450 cfs in above-normal and wet years. Also required is a 1-month pulse flow during the juvenile chinook salmon spring migration period, which ranges from about 3,000 cfs in dry years (3,110 cfs or 3,540 cfs) to more than 7,000 cfs in wet years (7,330 cfs or 8,620 cfs). The 1995 WQCP also specifies an October minimum flow of 1,000 cfs with an additional pulse flow that averages about 500 cfs in most years. Vernalis flows for the other months are not directly specified, but about 1,500 cfs will be required during the irrigation season of April through August to maintain electrical conductivity (EC) at levels that meet the objective of

700 microsiemens per centimeter (μS/cm), and about 1,000 cfs will be required in other months to meet an EC objective of 1,000 μS/cm.

Table 1 shows the expected San Joaquin River flows under the 1995 WQCP flow and salinity objectives simulated for the 1922-1991 period with California Department of Water Resources' (DWR's) DWRSIM monthly planning model (DWRSIM 472 results). Monthly minimum flows in the summer months will generally be maintained above 1,500 cfs for salinity control. The 80% exceedence flows for the summer months of June-September will be about 1,400 cfs. Vernalis flows of 2,000 cfs are simulated to occur about 50% of the time in June, but only about 10% of the time in July, August, and September. Because of the WQCP October flow objectives, simulated Vernalis flows in October will be greater than 1,000 cfs in every year and will be greater than 2,000 cfs in about 70% of the years. The 1995 WQCP does not include any flow requirements for the San Joaquin River downstream of Vernalis.

Head of Old River Hydraulics

Old River splits off from the San Joaquin River upstream of Stockton near Mossdale Landing (Figure 1). Because a large fraction of the San Joaquin River flow measured at Vernalis is diverted into Old River, flow in the San Joaquin River near Stockton is much less than the measured flow at Vernalis. The tidal and net flows in the San Joaquin River near the Stockton RWCF discharge are now directly measured by the UVM installed by the USGS in cooperation with the City of Stockton (described below under "U.S. Geological Survey UVM Measurements of Tidal Stage and Flow"). These UVM measurements, along with flow measurements from Vernalis, will enable the tidal flow split at the head of Old River to be accurately described.

Figure 3 compares the daily average UVM-measured flows at Stockton with the Vernalis flows for water year 1996. The minimum Vernalis flow during this period was about 1,500 cfs. Although Old River flow may be influenced by the rate of State Water Project (SWP) and Central Valley Project (CVP) pumping, regression analysis using the available data indicated that the river flow at Stockton is strongly correlated with the Vernalis flow. Figure 4 illustrates the linear statistical relationship between San Joaquin River flows at Stockton and Vernalis. The regression equation indicates that the daily average Stockton flow split is equal to 54% of Vernalis flow minus 613 cfs. For example, with a Vernalis flow of 2,000 cfs, the Stockton flow is estimated to be about 467 cfs. For a Vernalis flow of 1,500 cfs, the Stockton flow would be about 197 cfs. For a Vernalis flow of 1,000 cfs, the estimated Stockton flow would be upstream (reversed) at about -73 cfs (however, this has not been confirmed, as there are no Stockton UVM measurements with a Vernalis flow of less than 1,500 cfs yet). Factors affecting flows at Stockton under lower Vernalis flows remain to be evaluated (during future low-flow periods).

U.S. Geological Survey UVM Measurements of Tidal Stage and Flow

Measurements of tidal stage and flow are provided by the UVM station that was installed by USGS, in cooperation with the City of Stockton, in fall 1995. The UVM consists of a sound-wave transmitter and receiver oriented at an angle across the San Joaquin River. The station records the average flow velocity at the elevation of the UVM device (about -5 feet mean sea level [msl]). A series of boat surveys that record the entire river velocity profile with a boat-mounted Acoustic Doppler Current Profiler is used to calibrate the UVM data (Simpson and Oltmann 1992). The average velocity is converted to average flow based on the tide stage that is also recorded at the UVM station.

Figure 5 shows the hourly stage at the Stockton UVM station for September 1996. There are two tidal fluctuations (i.e., semidiurnal) each day. The spring-neap tidal cycle is evident in the monthly tidal record. The 25-hour moving average tide stage has a slight variation during the month of about 0.5 foot. The average tide stage is highest during neap tides, when the two tides are approximately equal in magnitude, and is lowest during spring tides, when the two tides are offset, with an extreme low tide and extreme high tide stage (i.e., September 6-8 and 18-20).

Figure 6 shows the hourly UVM tidal flow measurements for September 1996. The downstream (positive) flows during ebb tides (decreasing stage) are quite uniform, with a flow of slightly more than 2,000 cfs occurring for several hours. The upstream flows during flood tides (increasing stage) are less during spring tides, when the stage does not increase as much (or as fast) during one of the tides each day. The 25-hour moving average flow was about 805 cfs in September 1996, corresponding to an average Vernalis flow of 2,160 cfs. This is somewhat higher than the flow-split regression estimate of 553 cfs. CVP and SWP export pumping averaged 10,090 cfs in September 1996.

Figure 7 illustrates that the daily average tidal flows for the range of measured net flows at Stockton average about 2,000 cfs in the upstream direction during flood tides (rising stages) and about 2,000 cfs in the downstream direction during ebb tides (falling stages). The average tidal flows decrease to about 1,000 cfs when the net river flow increases to 8,000 cfs because the average river stage increases to above 4 feet (i.e., high tide) and, therefore, the tidal fluctuation is reduced at the UVM station.

Head of Old River Barrier (or Gates)

Temporary barriers have been placed in the Old River channel in the fall of many years since 1963 (Table 2) for maintenance of fishery habitat water quality conditions and attraction flows. A temporary barrier also was used in the spring of several recent years to improve the survival of outmigrating juvenile chinook salmon. The temporary barriers have consisted of a rock jetty that extends across the channel, with a top elevation of about 0 feet msl that is exposed at low tide. In some years, a portion of the temporary barrier has been left open as a submerged weir with an elevation of just below minimum tide (i.e., minus 1.0 foot). Therefore, the temporary barrier allows some flow into Old River during most of the tidal cycle because the tidal stage is usually greater than 0 feet. DWR has made flow measurements in several years and estimated that the barriers have kept about 50% to 75% of the Vernalis flow in the San Joaquin River downstream of the head of Old River (and at Stockton). This is considerably more flow than would remain in the San Joaquin River channel without the rock barrier.

DWR and the U.S. Bureau of Reclamation have investigated use of a gate at the head of Old River as part of the Interim South Delta Program (ISDP), which would (1) protect migrating fish from the Delta exports located along Old River downstream of Tracy in the spring (April and May) and (2) increase flows and increase DO concentrations in October, when chinook salmon are assumed to be migrating upstream past Stockton. Current DWR plans include installing operable radial gates for the head of Old River structure. All south Delta channel barriers are designed with gates similar to those in the Suisun Marsh Salinity Control Gate in Montezuma Slough near Collinsville.

Installation of a gate at the head of Old River is specified as one of the required actions in the Central Valley Project Improvement Act (CVPIA) and is generally described in the "Dissolved Oxygen and Circulation Solutions" section of the San Joaquin River Management Plan (California Department of Water Resources 1995). An operable gate at the head of Old River is an element in the Proposed Agreement on San Joaquin River Protection offered by the San Joaquin River Interests and CVP/SWP Export Interests to the SWRCB in May 1996 (San Joaquin River Interests and CVP/SWP Export Interests 1996). The ISDP facilities are generally included in several of the CALFED Delta configurations.

The SWRCB draft EIR for implementation of the 1995 Bay-Delta WQCP includes an analysis of several alternatives for meeting the 6-mg/l DO objective in the Stockton Deepwater Ship Channel. Because the 6-mg/l DO objective is applicable during the September-November period, the SWRCB alternatives assume that the head of Old River gates would be closed during this 3-month period. (California State Water Recources Control Board 1997.)

The possible benefits of achieving higher DO concentrations as a result of increased flow in the San Joaquin River at Stockton in summer and fall have not been previously studied with a quantitative comparative tool such as the Stockton water quality model. Results from the Stockton water quality model have been presented to SWRCB staff for use in the draft EIR for implementation of the 1995 Bay-Delta WQCP. As shown later in this report, the Stockton water quality model indicates that flows have a substantial effect on DO concentrations in the San Joaquin River. Installing an operable tidal gate at the head of Old River may be a very effective way to increase flows past Stockton and thereby increase DO concentrations along the portion of the San Joaquin River between Stockton and Turner Cut.

HISTORICAL SAN JOAQUIN RIVER WATER QUALITY CONDITIONS

The historical water quality data provide the most reliable indicator of conditions and factors that control DO concentrations in the San Joaquin River near Stockton. This section describes water quality variables and measurements of historical water quality conditions in the San Joaquin River near Stockton. The effects of each major process affecting DO concentrations can be identified from these historical water quality data. The Stockton water quality model has been calibrated by adjustment of some model coefficients to match the available measurements of water quality in the vicinity of Stockton.

Effects of San Joaquin River Geometry on Water Quality Processes

The geometry of the San Joaquin River channel controls many of the hydrodynamic conditions and water quality processes that affect DO concentrations near Stockton (Figure 8). The San Joaquin River upstream of the Stockton Deepwater Ship Channel is relatively narrow and shallow. The San Joaquin River downstream of Stockton is much wider and deeper because it is dredged to a depth of 35 feet to maintain the Deepwater Ship Channel. The discharge from the Stockton RWCF is located just upstream of the Deepwater Ship Channel.

Table 3 summarizes the geometry of the San Joaquin River channel between the head of Old River and Turner Cut. The San Joaquin River between the head of Old River and the turning basin of the Deepwater Ship Channel is about 13.6 miles long and increases in width from about 150 feet at the upstream end to about 250 feet at the downstream end. At low tide (i.e., 0 feet msl), the surface area of this reach is about 304 acres, and mean depth is 8.1 feet. At high tide (i.e., 4 feet msl), the surface area increases to about 340 acres and mean depth increases to 10.8 feet. The total volume of this section of river is about 2,458 acre-feet (AF) at low tide and about 3,692 AF at high tide (Table 3, columns H and I). A net flow of 500 cfs (i.e., 1,000 AF per day) would have a travel time of about 3 days in this upstream section of the river. With a flow of 1,000 cfs, travel time would be reduced to 1.5 days.

The San Joaquin River downstream of the turning basin to Turner Cut is about 8.7 miles long and varies in width from about 500 feet at the upstream end to about 1,000 feet at Turner Cut. At low tide, the surface area is about 727 acres and mean depth is about 21.8 feet. At high tide, the surface area is about 756 acres and mean depth is 24.8 feet. The total volume of this downstream section of the river is about 15,827 AF at low tide and about 18,750 AF at high tide (Table 3, Columns H and I). The turning basin itself has a volume of 2,876 AF at low tide and 3,388 AF at high tide with a mean depth of 23 feet. A net flow of 500 cfs would have a travel time of about 20 days in this downstream section of the river (because the turning basin volume is tidally mixed with the Deepwater Ship Channel volume). With a flow of 1,000 cfs, travel time would be reduced to about 10 days.

The mean depth is a very important factor controlling the effects of surface reaeration and sediment oxygen demand (SOD) on the DO concentration. Because the mean depth is much greater in the Deepwater Ship Channel than upstream, surface and bottom processes have less effect on DO concentrations in the Ship Channel portion of the river. The effects of reaeration are smaller in the Deepwater Ship Channel because the depth is greater. The channel depth also has a large effect on algal photosynthesis and respiration. Because the turbidity of the San Joaquin River is relatively high, light penetration is limited and the fraction of the water column that supports photosynthesis and algae growth is much smaller in the Deepwater Ship Channel section of the river than upstream.

Water Quality Variables Related to Dissolved Oxygen Concentrations

This section describes the water quality variables that are used as indicators of the processes that supply oxygen and remove it from the river.

Water temperature is the most important factor (atmospheric pressure has a small effect) determining the amount of oxygen that can be dissolved in water when saturated: the colder the water, the more oxygen it can hold in solution before becoming saturated. The saturation DO concentration is important because the amount of oxygen that can be transferred by reaeration processes from the air to the water is directly proportional to the difference between saturation DO concentration and the actual DO concentration (i.e., the DO deficit).

BOD is a bioassay-based measure of organic matter that is readily decomposable (usually within 5 days) in a water sample; the higher the BOD, the more oxygen will be consumed by the organic matter dissolved or suspended in the water. Because BOD requires a 5-day bioassay procedure, it is not often measured in standard water quality surveys.

Ammonia is an important variable because nitrification (i.e., oxidation) of ammonia to nitrate consumes a considerable amount of oxygen. For example, nitrification of 1 mg/l of ammonia-N to nitrate will require 4.5 mg/l of DO. Nitrate-nitrogen (nitrate-N) is an important indicator of the fraction of ammonia that has been oxidized. Both ammonia and nitrate can supply nitrogen for algal growth.

Total suspended solids (TSS) and turbidity provide information about the concentration of particulates. TSS concentrations are determined by filtering and weighing of a sample, whereas turbidity is determined by an optical (i.e., scattered light) measurement. Fine particles may have a turbidity value (NTU) about equal to the TSS concentration (mg/l), but TSS is generally higher than turbidity.

Light penetration is measured as Secchi depth, the depth to which a Secchi disk (i.e., disk painted with black and white pattern) is lowered until it cannot be seen. Secchi depth (m) and turbidity (NTU) are inversely correlated. The Secchi depth represents approximately 10% of ambient light, so the 1% light depth (approximate euphotic depth) is about twice the Secchi depth.

Volatile suspended solids (VSS) concentration provides an approximate measure of the organic materials suspended in the water (measured by high-temperature combustion of the TSS sample). The relationship between VSS and the resulting BOD is difficult to determine because the composition of VSS and its susceptibility to microbial decomposition is variable, but 1 mg/l of VSS is generally equivalent to 1mg/l of BOD. VSS that does not decay rapidly in the water column may settle and contribute to SOD.

Algal biomass is approximated from measurements of chlorophyll concentration. Algal chlorophyll is often about 1% of the algal biomass (e.g., 10 micrograms per liter [μg/l] of chlorophyll would be about 1 mg/l of biomass that would be measured as VSS). Algal biomass is relatively easy for bacteria to consume, so the organic matter transported by the river during the summer months is expected to exert a high oxygen demand (i.e., 10 μg/l of chlorophyll would be equivalent to 1mg/l of BOD).

Water Quality Sampling Programs

Table 4 summarizes information on a number of routine water quality monitoring programs that include sampling stations within the reach of the San Joaquin River of importance to this assessment of DO management alternatives.

DWR operates continuous water quality monitoring devices at Mossdale (upstream of the head of Old River) and in the Stockton Deepwater Ship Channel (downstream end of Rough and Ready Island, opposite the Calaveras River channel). These monitors provide hourly measurements of temperature, DO, EC, and pH. The data from these monitors extend back to 1984.

DWR measures surface and bottom temperature and DO in a series of longitudinal grab samples it collects in the San Joaquin River at several stations extending from Vernalis to Prisoner's Point. The purpose of the sampling is to help evaluate the effects of the temporary barrier at the head of Old River on downstream DO concentrations. This program began in 1969, and several longitudinal surveys are performed each year that the barrier is installed.

DWR also collects samples on a biweekly (summer) or monthly (winter) schedule for the SWRCB (D-1485) water quality monitoring program, which includes three stations within the study reach at Vernalis, Mossdale, and Buckley Cove (opposite Rough and Ready Island). Measurements are taken of temperature, DO, TSS and VSS, chlorophyll, total and dissolved phosphorus, nitrite, nitrate, ammonia nitrogen and organic nitrogen, turbidity, and Secchi depth. Data from this program are available starting from 1975.

The Stockton RWCF collects water quality samples at eight river stations: two upstream and six downstream of its effluent discharge location. Grab samples are collected generally once per day during summer months and less frequently during winter. These samples are analyzed for temperature; DO; pH; turbidity; ammonia, nitrate, nitrite, and Kjeldahl nitrogen; and Secchi depth.

During a special NPDES study conducted during 1990-1991 to calibrate the Stockton water quality model, the river sampling program also included measurements of BOD and chlorophyll concentration.

FACTORS AFFECTING DISSOLVED OXYGEN BALANCE IN THE SAN JOAQUIN RIVER NEAR STOCKTON

Figure 9 shows a conceptual diagram of the major processes influencing DO in the San Joaquin River near Stockton that are included in the Stockton water quality model. Changes in these controlling processes can be simulated to evaluate the sensitivity of DO concentrations to the processes and the effectiveness of alternative approaches for managing San Joaquin River DO. Each of the modeled processes influencing DO concentrations is discussed in this section to provide a framework for understanding the model results used to evaluate alternatives for San Joaquin River DO management.

Upstream River Water Quality

Water quality of the San Joaquin River upstream of Stockton is a function of hydrology, geology, soils, and land use practices throughout the San Joaquin River watershed (i.e., nonpoint sources). Most of what is known about water quality upstream of Stockton is based on the DWR monitoring at Vernalis and Mossdale. Unfortunately, this sampling program does not include measurements of BOD. Consequently, direct long-term comparisons between river BOD loads and BOD loading from point sources are not possible. The Stockton RWCF sampling in 1990 and 1991 included BOD measurements that ranged from 1 to 5 mg/l at the upstream station. The DWR sampling program does measure chlorophyll concentration and VSS, which can be used to estimate river BOD.

Comparison of TSS measurements at Vernalis, Mossdale, and Buckley Cove indicates that TSS concentrations are highest at Vernalis, are slightly less at Mossdale, and are substantially less at Buckley Cove. This generally indicates that settling of particulates occurs between Vernalis and Stockton. Measurements of turbidity and Secchi depth confirm that there is considerable settling of particulates in the San Joaquin River.

The monthly average VSS concentrations in the San Joaquin River at Vernalis, Mossdale, and Buckley Cove are shown in Figure 10. The highest average concentrations of about 10 mg/l are found in the summer months at Vernalis and Mossdale. The lowest VSS concentrations are generally observed in the winter months. Monthly median VSS concentrations decrease slightly between Vernalis and Mossdale and are about 3-4 mg/l at Buckley Cove. Some fraction of the VSS material measured at the Mossdale station is transported into the San Joaquin River downstream of the head of Old River and settles onto the channel bottom and contributes to the SOD. Because the rate of biochemical decay is reduced in winter, VSS material may accumulate in winter.

The contribution of VSS to SOD may roughly be estimated as follows: organic matter is approximately 40% carbon, and carbon will eventually be oxidized into CO_2, at an oxygen-to-carbon weight ratio of 2.7, so 1 mg/l of organic VSS will require about 1 mg/l of oxygen to be fully oxidized (1 mg/l VSS x .40 carbon/VSS x 2.7 oxygen/carbon = 1 mg/l oxygen). The decrease of about 5 mg/l of VSS between Mossdale and Buckley Cove in the summer months may therefore be associated with a substantial organic loading of about 5 mg/l that produces either increased BOD in the water column or increased SOD on the bottom.

Figure 11 shows the monthly average chlorophyll concentrations at Vernalis, Mossdale, and Buckley Cove. Chlorophyll levels in the San Joaquin River near Mossdale often exceed 100 μg/l, with blooms producing maximum chlorophyll concentrations of more than 200 μg/l. Monthly average chlorophyll concentrations generally range from less than 20 μg/l during December-February to more than 50 μg/l during June-August. Median chlorophyll increases slightly between Vernalis and Mossdale, and then decreases to about 10 μg/l at Buckley Cove. Although algae is apparently still able to grow in the San Joaquin River upstream of Mossdale, conditions are less favorable for continued growth downstream because of low light conditions in the Deepwater Ship Channel.

If algal biomass contains about 1% chlorophyll, a chlorophyll measurement of 10 μg/l would correspond to algal biomass (VSS) of 1 mg/l. Based on this conversion factor, it is estimated that during the summer months (May-October), about half the VSS in the San Joaquin River near Vernalis consists of algal biomass. During the winter months, by contrast, algal biomass makes up less than 25% of the VSS. The likelihood that the VSS loading settles in the tidal portion of the San Joaquin River suggests that a large fraction of observed SOD may originate as VSS from the San Joaquin River inflow.

These river water quality measurements provide the basis for estimating the historical river loads. If the flow split at the head of Old River discussed above is used to estimate flows past Stockton, the average river load to the Deepwater Ship Channel can be estimated as:

Daily load (lbs/day) = 5.4 * Stockton River Flow (cfs) * Concentration (mg/l)

Table 5 provides monthly average river flow, concentrations, and estimated river loads for several of the water quality variables measured at Mossdale for 1987 to 1995.

Continuous Dissolved Oxygen Monitoring at Mossdale and the Stockton Deepwater Ship Channel

DO measurements from the continuous monitoring stations at Mossdale and the Stockton Deepwater Ship Channel (near the downstream end of Rough and Ready Island, opposite the mouth of the Calaveras River channel) have been summarized with daily minimum and maximum DO concentrations. Figures 12a-12l show the daily minimum and maximum DO at Mossdale and Stockton for 1985 through 1996. Measured DO at Stockton is almost always less than DO at Mossdale. Because saturation concentration is lower when temperatures are higher, the saturated DO concentration is only about 9 mg/l during summer. The DO saturation concentration at Mossdale (calculated from the minimum daily temperature) is also shown to indicate periods with supersaturated conditions (DO levels that temporarily exceed saturation concentration). These episodes generally coincide with periods of high chlorophyll concentrations at Mossdale and Vernalis and are thus almost certainly the result of algal photosynthesis. Measurements of elevated pH also confirm the high level of algal photosynthesis (because the uptake of CO_2 raises the pH of water with moderate alkalinity).

During most years, these periods of supersaturated DO conditions (high algal production) at Mossdale are associated with extremely low DO levels in the Stockton Ship Channel, some 20 river miles downstream. There is often a time lag between the elevated DO at Mossdale and the depressed DO at Stockton. Examples of this relationship between high algal production at Mossdale and depressed DO concentrations near Stockton occurred during 1991 (September and October), 1992 (September and October), and 1993 (July and August).

Stockton RWCF Effluent Concentrations and Loads

The Stockton RWCF uses trickling filters and secondary clarifiers followed by facultative oxidation ponds for secondary treatment that cover about 1 square mile (640 acres). Mean depth averages 4-5 feet in the oxidation ponds and hydraulic residence time is relatively long compared with that of conventional wastewater treatment plants, averaging about 30 days. Each oxidation pond consists of an aerobic surface layer that supports vigorous algal growth and aerobic bacterial production. This aerobic water is underlain by an anaerobic sludge layer formed by the deposition of large organic particulate matter. Soluble and colloidal materials in the surface water are oxidized by aerobic and facultative bacteria using oxygen produced by algal photosynthesis and surface aeration. Carbon dioxide produced by the bacteria in turn serves as an inorganic carbon source for the production of new algal biomass. Anaerobic breakdown of the sludge layer solids generates dissolved organic matter; carbon dioxide; methane; and hydrogen sulfide gas, which is either oxidized in the surface layer or lost to the atmosphere.

The Stockton RWCF operates tertiary treatment facilities at certain times of the year. Tertiary treatment of the pond discharge consists of floatation and skimming (to remove the algal biomass) with filtration of the final effluent. The large oxidation ponds allow temporary storage of effluent; the Stockton RWCF does not discharge every day, in order to reduce the costs of operating the tertiary treatment processes. On days with discharge to the river, the RWCF routinely measures temperature, DO, BOD, TSS, VSS, total organic carbon, total dissolved solids, four forms of nitrogen (ammonia, nitrite, nitrate, and organic), and total phosphorus concentration.

Figures 13a-13g show the daily measured Stockton RWCF effluent concentrations of BOD, ammonia, and VSS for water years 1990 to 1996. Each year has a slightly different pattern of daily concentrations and corresponding effluent loads. The BOD measurements were generally within the range of 5 to 25 mg/l. The lowest BOD concentrations were generally in the summer and fall months. The highest BOD concentrations were in winter.

The historical Stockton RWCF ammonia concentrations ranged from less than 1 mg/l in spring and early summer to about 20 mg/l in the winter months. Because the ammonia oxidation represents a relatively large part of the RWCF demand on DO concentrations, the specific pattern of ammonia concentration during periods of low DO can be important. In some years (e.g., 1990 and 1994) ammonia concentrations remained relatively low during August and September, while in other years (e.g., 1992 and 1996) the ammonia concentrations were increasing in August and were relatively high in September.

The Stockton RWCF VSS concentrations were generally in the range of 10 mg/l to 30 mg/l. Sometimes VSS concentrations were similar to the BOD measurements, and other times they were up to twice the BOD measurements.

These data provide the basis for calculating effluent loads to the river. Daily loads can be estimated from effluent flow and concentrations as:

$$\text{Daily Load (lbs/day)} = 5.4 * \text{Effluent Flow (cfs)} * \text{Concentration (mg/l)}$$

The monthly average RWCF effluent discharged to the river generally ranges between 30 and 40 cfs (Table 6a). The highest effluent discharge periods generally coincide with the wet season (November-March) and with the food processing season (July-September). BOD of the effluent is generally less than 20 mg/l during winter and decreases to less than 10 mg/l during the dry season (April-October). Consequently, BOD loading to the river displays a distinct seasonal pattern, with the lowest values of less than 2,000 lbs/day between April and October (Table 6b). During this period, a high percentage of the algal biomass and other potentially oxygen-demanding organic matter present in the pond effluent are removed by tertiary treatment processes before the final effluent is discharged to the river.

The seasonal pattern of ammonia-N concentration in the final effluent is more pronounced than that of BOD (Table 6c). Ammonia-N concentrations generally range between 15 and 25 mg/l during winter months and decline to less than 5 mg/l during the dry season. Some nitrification may occur at warmer temperatures, but the relatively low effluent nitrate concentrations indicate that the ammonia pattern results primarily from the increased algal production that accompanies higher light intensity during summer months. Ammonia and other forms of nitrogen from the water column are incorporated into algal biomass, which is subsequently filtered out of the effluent and recycled back to the oxidation pond system. Consequently, ammonia-N loading to the river increases from less than 500 lbs/day during summer months to greater than 3,000 lbs/day during winter months (Table 6c). Lower algal production levels presumably account for the higher ammonia levels of pond effluent during the darker, cooler winter months.

The estimated BOD equivalent of ammonia-N in the final effluent (based on 4.5 mg/l of DO being required to nitrify 1 mg/l of ammonia-N) ranges from less than 10 mg/l in summer to about 100 mg/l in winter (Table 6d). These values suggest potential nitrogenous oxygen demands of less than 1,000 lbs/day during certain summer months and more than 15,000 lbs/day during winter months.

The VSS measurements indicate that the Stockton RWCF effluent contains substantial concentrations of organic particulates (Table 6e). Because the VSS and BOD measurements are similar in magnitude, most of the VSS is apparently decayed within the 5-day BOD test. The VSS particulates that are not consumed in the 5-day BOD test may settle and contribute to SOD in the river channel upstream and downstream of the effluent.

Comparison of effluent loads (Table 6) with river loads (Table 5) indicates that the river loads may be greater in magnitude. For example, average September effluent loads are about 2,000 lbs/day of BOD and 10,000 lbs/day of ammonia. The average estimated river load from VSS is about 24,000 lbs/day.

Temperature-Dissolved Oxygen Saturation

Continuous monitoring data from the Stockton Deepwater Ship Channel station (Rough and Ready Island station) indicate that monthly average water temperature increases from about 9°C (48°F) in January to a summer peak of about 25°C (77°F) in July and August (Table 5f). The amount of oxygen the water can hold in solution (saturation DO concentration) therefore decreases from about 12 mg/l in January to about 8 mg/l during July and August (Table 5f). The saturation DO concentration provides a practical upper limit for DO concentration. Photosynthesis from algae can produce supersaturated conditions (e.g., at Mossdale), but the DO concentration will return to saturation by exchange with the atmosphere. Aeration devices can increase the DO concentration only to the saturated concentration.

Algal Photosynthesis and Respiration

Algae produce oxygen during photosynthesis, but oxygen is also consumed by algae for respiration and after the algae die and decay. The net effect of algae on DO will depend on the depth of the river segment relative to the euphotic depth (i.e., lighted depth) and the estimated rates of growth, respiration, and settling of algae. High levels of algal biomass prevail in the San Joaquin River at Vernalis and Mossdale because the river offers an abundant supply of phosphorus and nitrogen, as well as sufficient light, for algae production.

The algae responsible for the high chlorophyll levels that prevail at Mossdale are primarily diatoms (Ball 1979). Most of the diatoms are adapted to stream conditions in that they depend on the turbulence of stream flow to stay in suspension and are capable of surviving and actively photosynthesizing if they temporarily settle out onto shallow sediments. When these algae are transported to the much deeper water of the San Joaquin River channel between Old River and Stockton (9 feet mean depth) or the Deepwater Ship Channel (23 feet mean depth), they encounter conditions for which they are poorly adapted. Consequently, most of the algal biomass transported into this reach of the San Joaquin River settles to the dark river bed as VSS and decomposes. The decomposition of this algal biomass is assumed to contribute to the SOD.

Sediment Oxygen Demand

The largest modeled DO loss term is the SOD. SOD is the result of chemical oxidation and respiration processes (i.e., decay) on the bottom of the river. Measured SOD rates from other rivers range from less than 1 g-O_2/m^2/day to more than 5 g-O_2/m^2/day. An SOD rate of 1 g-O_2/m^2/day is about 9 lbs/acre/day. The total daily oxygen demand from the 1,000 acres of bottom sediment from the head of Old River to Turner Cut (including the turning basin) is therefore about 9,000 lbs/day for each 1 g-O_2/m^2/day of estimated SOD rate.

The SOD potentially contributed from inflowing algal biomass and other VSS can be estimated. Assuming a flow of 500 cfs, each 1 mg/l of VSS represents a load of 2,700 lbs/day. If all of the VSS settles out evenly between Old River and Turner Cut (a total area of about 1,000 acres), the decomposition of each 1 mg/l VSS in the assumed river flow of 500 cfs would exert an average SOD of about 0.3 g-O_2/m^2/day. Because the VSS concentrations are in the range of 5 mg/l to 10 mg/l, the potential SOD contributed by an assumed river inflow of 500 cfs would be 1.5 to 3.0 g-O_2/m^2/day.

The modeled estimates of SOD range from about 1.2 to 3.0, with an average of about 2.0 g/m^2/day. The highest SOD rates are estimated for the shallow segments upstream of the Stockton RWCF. The Stockton water quality model assumes that SOD rates are maintained by the accumulation of particulate materials from river or effluent sources.

Biochemical Oxygen Demand

The BOD is assumed to oxidize (i.e., decay and consume DO) at a rate that increases with higher water temperature. The Stockton water quality model assumes a BOD decay rate of 0.15 per day at 20°C. With this decay rate, about half (56%) of the BOD material is oxidized in the first five days (i.e., $1- 0.85^5$).

The daily effect of BOD on the DO concentration is approximately the BOD concentration multiplied by the daily decay rate. The daily decrease in DO would therefore be about 0.15 mg/l for each 1 mg/l of BOD. The total effect of BOD on DO concentration is equivalent to the BOD concentration. A river load BOD of 2 mg/l will ultimately require 2 mg/l of oxygen. The Stockton RWCF discharges a maximum of 20 mg/l BOD in winter (10 mg/l BOD in summer) that will be mixed into the river channel by tidal flows and diluted by the net river flow. Because the maximum discharge is about 50 cfs, the maximum expected effect of the RWCF discharge BOD on river DO concentrations for a river flow of 1,000 cfs would be a decrease of about 1 mg/l (i.e., 50 cfs/1,000 cfs x 20 mg/l) in winter and 0.5 mg/l in summer.

Ammonia Oxidation

River ammonia concentrations are quite low at Mossdale, so the largest known source of ammonia in the Deepwater Ship Channel is the Stockton RWCF effluent. Table 6c indicates that the Stockton RWCF effluent ammonia concentrations have averaged about 4.8 mg/l in April, 2.4 mg/l in May, 1.6 mg/l in June, 1.5 mg/l in July, 5.6 mg/l in August, 12.5 mg/l in September, and 16.1 mg/l in October through February. Ammonia concentrations can represent an important oxygen demand if net river flow is low (Table 6d). The modeled nitrification rate is relatively slow, 0.09 per day, but the ultimate oxygen demand is about 4.5 times the ammonia concentration.

Reaeration

Reaeration is the major source of oxygen in the San Joaquin River near Stockton, replenishing the DO lost by BOD and ammonia oxidation. The Stockton water quality model uses the O'Conner-Dobbins equation, which estimates the reaeration rate as a function of water velocity and depth:

$$K2 = 6 * V^{0.5} / H^{1.5}$$

where K2 is the reaeration rate in units of day $^{-1}$, V is velocity in ft/sec, and H is depth in feet. The rate of change in DO concentration in the river from reaeration can be estimated as:

$$\text{DO increase (mg/l per day)} \\ = K2 * [\text{DO saturation (mg/l)} - \text{DO concentration (mg/l)}]$$

The reaeration rate is therefore approximately the fraction of the DO deficit that will be replenished in a day. The magnitude of reaeration increases as the DO deficit increases. In the San Joaquin River upstream of the Stockton RWCF discharge, the average tidal velocity is about 0.75 ft/sec and the average depth is about 9 feet. The expected reaeration coefficient (K2) is therefore about 0.20 day $^{-1}$. For a DO deficit of 3 mg/l, reaeration would add about 0.6 mg/l each day in this upstream segment (i.e., 0.2 x 3 mg/l). However, downstream in the Deepwater Ship Channel the average depth is about 20 feet and the average tidal velocity is only about 0.25 ft/sec. The K2 value is therefore only about 0.03 day $^{-1}$. For a DO deficit of 3 mg/l, reaeration would add only about 0.1

mg/l per day. A larger DO deficit will therefore develop in the downstream Deepwater Ship Channel than in the upstream segments.

Reaeration will be increased by surface winds that may be relatively high in the Delta. The reaeration rate has been estimated from laboratory and field measurements to increase with wind speed squared:

$$K2(\text{wind \& water}) = K2(\text{water}) + 0.015 * \text{wind (ft/sec)}^2 / \text{depth (ft)}$$

Measurements of wind speed from the vicinity of Stockton indicate that a typical wind speed on summer days is 6.5 feet per second (ft/sec), which would likely increase the reaeration in the Ship Channel section of the river from 0.03 to 0.06 day $^{-1}$. A wind speed of 13 ft/sec would increase the reaeration to about 0.15 day $^{-1}$. Some of the observed variation in DO concentrations may potentially be caused by fluctuations in the reaeration rate caused by variable wind speed.

Stockton Deepwater Ship Channel Aeration Device

Because of the assumed effects of channel deepening on San Joaquin River DO concentrations, the U.S. Army Corps of Engineers (Corps) has been conducting instream aeration in the San Joaquin River near the Port of Stockton as mitigation for potential impacts on DO levels caused by Corps dredging of the Stockton Deepwater Ship Channel. The aeration system has been in operation since fall 1993 and generally operates from September 1 through November 30. The Corps estimated that the dredging project would cause a decrease of about 0.4 mg/l (approximately 2,000 pounds per day [lbs/day] of oxygen at a river flow of 1,000 cfs) in a 15-mile stretch of the deepened channel. The Corps agreed to mitigate the potential impact by installing and operating an aeration system consisting of two manifolds, each with eight mixing nozzles that introduce a jet of water mixed with air bubbles into the river. The aeration system jet, which is lowered to about a 20-foot depth, is designed to inject about 2,000 lbs/day of DO into the San Joaquin River at the confluence with the Deepwater Ship Channel, just downstream of the RWCF discharge (see Figure 1).

Another method for stream aeration that uses a waterfall design, called side-stream aeration, is being used in the Chicago area (Civil Engineering 1994). There may be other methods that could be used in the San Joaquin River for stream aeration or oxygen injection. The effects of aeration have been simulated with the Stockton water quality model to evaluate the effectiveness of aeration devices as alternatives for meeting the DO objectives near Stockton. More detailed evaluations of the feasibility and benefits of various aeration methods are in progress.

MODEL RESULTS

The Stockton water quality model results were compared with tidal flow measurements and water quality measurements to confirm that the model results can be used for an accurate comparative evaluation of DO management alternatives. This calibration is described more fully in Schanz and Chen (1993).

Tidal Flows

Tidal flows are important because they control the mixing and dilution of the Stockton RWCF effluent during periods of relatively low river flow. Three downstream tidal boundaries (San Joaquin River, Turner Cut, and Disappointment Slough) are specified in the model based on stage measurements at Venice Island (time and stage for each high and low tide) or the ocean tides at the Golden Gate Bridge. The tidal stage variation is relatively uniform in the San Joaquin River. The tidal stage variation at Venice Island is about 4 feet, with low tide at about 0 feet msl and high tide at about 4 feet msl. The tidal stage variation is also about 4 feet at the RWCF discharge and at the upstream end of the model.

The model results indicate that the average tidal flow is about 4,000 cfs at the downstream end of the model near Turner Cut, about 2,000 cfs at the RWCF (UVM station), and about 1,000 cfs at the upstream end at the head of Old River. For reference, the RMA Delta Hydrodynamic Model used by the Corps and the DWRDSM hydrodynamic model used by DWR give similar results.

Comparisons between the simulated and measured tidal stage and tidal flow fluctuations indicate that the mixing caused by the substantial tidal flows near Stockton are adequately represented in the Stockton water quality model. The assimilative capacity resulting from tidal mixing is most important during periods of low net flow at Stockton (e.g., less than 1,000 cfs) and becomes less important as the net downstream flow increases.

Net Flow and Mixing at Stockton

The Stockton water quality model uses an equation for estimating Stockton flows (when the head of Old River barrier is open) as a function of Vernalis flow and export pumping that was provided by DWR, which was based on DWRDSM hydrodynamic model results:

$$\text{Stockton Flow (cfs)} = 0.42 \text{ Vernalis Flow (cfs)} - 0.0873 * \text{Exports (cfs)} - 100$$

With this equation, a Vernalis flow of 2,000 cfs with relatively high export pumping of 10,000 cfs results in an estimated flow at Stockton of -133 cfs. For a Vernalis flow of 2,000 cfs and export pumping of 5,000 cfs, the Stockton flow is estimated to be 304 cfs. These are lower estimated net flows than indicated by the UVM station for a Vernalis flow of about 2,000 cfs (Figure 3).

The location of the highest contribution from the RWCF effluent that is governed by the net river flow can be determined from the phosphorus and ammonia concentrations (used as tracers of the effluent) because the effluent concentrations of these compounds are substantially higher than the river concentrations during winter and spring. In summer, when the effluent ammonia and phosphorus concentrations are low, these variables cannot be used as tracers for the effluent. For example, Figure 14 shows a comparison of concentrations of phosphorus at Station R2 (upstream) and Station R3 (downstream) for water year 1991. During winter and spring, the concentrations are similar at the two stations, suggesting that the effluent generally remained centered at the discharge location (net flow of 0 cfs). Simulated phosphorus concentrations at Stations R2 and R3 suggest that the model is accurately simulating the net movement and tidal mixing of the effluent during this period of low net flow. The effect of a relatively modest flow increase at the end of March was accurately simulated when the phosphorus concentration at Station R2 (upstream) was reduced substantially more than the corresponding phosphorus concentration at Station R3 (downstream).

Figure 15 shows that a nearly identical pattern was simulated and measured for ammonia concentrations in 1991. The effect of the flow increase at the end of March was accurately simulated. Although the net flow at Stockton may be somewhat uncertain when Vernalis flow is less than 2,000 cfs, the overall assimilation from tidal mixing of the effluent plume during periods of relatively low net flow are accurately simulated with the Stockton water quality model.

Dissolved Oxygen Concentrations

The Stockton water quality model results for three years (1991, 1993, and 1996) have been presented in the technical report evaluating DO management alternatives prepared for the SWRCB staff (Chen and Tsai 1997). The simulated DO concentrations generally match the measured DO concentrations for a wide range of river flow and RWCF effluent conditions. Therefore, results from the comparative simulations of water quality management alternatives can be used with confidence. Because the simulated DO concentrations are the net result of the other modeled processes and conditions, and because the DO objectives are not always achieved under current conditions, the effects of various water quality management alternatives on DO concentrations are compared in the next section.

COMPARATIVE ASSESSMENT OF DISSOLVED OXYGEN MANAGEMENT ALTERNATIVES

The results of the comparative assessment simulations with the Stockton water quality model are described here to provide information for evaluation of alternatives for meeting the general 5-

mg/l DO objective for the San Joaquin River and the 6-mg/l DO objective for September-November for the river between Stockton and Turner Cut.

The Stockton water quality model has been calibrated using the field data for 1991 and verified with 1993 and 1996 field data. However, to simplify these comparisons, the measured 1996 upstream and downstream river conditions (temperature, DO, and algae) and 1996 Stockton RWCF discharge concentrations (BOD and ammonia) have been used with constant specified net river flows to demonstrate the effects of alternatives involving (1) flow management, (2) Stockton RWCF effluent load reduction, (3) river reaeration, and (4) reduced upstream sources of SOD.

Simulations of DO concentrations at four of the Stockton RWCF monitoring stations—R1, R3, R5, and R7 (designated as Stations 1, 3, 5, and 7 in the accompanying graphs)—were used to describe the effects of management alternatives on San Joaquin River DO concentration. Station R1 is located downstream of the head of Old River. Station R3 is one mile downstream of the discharge at the confluence of the San Joaquin River and the Deepwater Ship Channel. Station R5 is at the downstream end of Rough and Ready Island opposite the Calaveras River and near the location of the continuous DO monitor. Station R7 is at Turner Cut. The 6-mg/l DO objective apparently applies to the San Joaquin River roughly between Station R3 and Station R7.

Simulated Effects of Changes in Flow on Dissolved Oxygen Concentration

Simulated DO concentrations were compared for 1996 levels of RWCF discharge at constant assumed San Joaquin River flows of 0 cfs, 500 cfs, and 1,000 cfs at Stockton.

Zero River Flow at Stockton

Figure 16 shows the simulated DO concentrations for a net river flow of 0 cfs (i.e., tidal flows only). Under a net river flow of 0 cfs, all of the oxygen demands remain in the river channel with only tidal mixing to dilute and transport the loads upstream and downstream. The simulation begins with the entire river at an assumed DO concentration of 8 mg/l. The lowest DO is simulated generally for Station R3. Simulated DO concentration at Station R3 declines to about 4 mg/l in November, February, March, and August. The lowest DO at Station R3 is simulated to be about 2 mg/l in September for these assumed conditions of no net flow. Simulated DO concentrations at Station R1 are not as low as at Station R3 because reaeration is stronger in this upstream segment. Simulated DO at Station R5 is about 1 mg/l higher than at Station R3 because less oxygen demands are mixed downstream to Station R5 and water from the downstream boundary has a greater influence at Station R5 through tidal mixing. The simulated DO at Station R7 remains relatively high and about 2-3 mg/l less than saturated DO. The monthly average DO concentrations at each measurement station for a net flow of 0 cfs are given in Table 7.

River Flow of 500 cfs at Stockton

Figure 17 shows the simulated DO concentrations for a net river flow of 500 cfs. The average travel time to Station R7 is about 20 days with a flow of 500 cfs. At this assumed net flow, the oxygen demands are transported farther downstream as a result of the net flow and tidal mixing effects. Simulated DO at Station R1 is dominated by the assumed river inflow concentration and remains higher than 6 mg/l except for one episode at the end of July when the estimated inflow DO concentration drops to about 5 mg/l. Simulated DO concentrations for Stations R3 and R5 are very similar. The DO at Station R7 remains relatively high but is reduced to less than 6 mg/l in August and September because the net flow of 500 cfs transports more of the oxygen demands toward Station R7, and the tidal exchange of water from the downstream boundary is reduced. The monthly average DO concentrations at each measurement station for a net flow of 500 cfs are given in Table 8.

River Flow of 1,000 cfs at Stockton

Figure 18 shows the simulated DO concentrations for a net river flow of 1,000 cfs. The average travel time to Station R7 is about 10 days with a flow of 1,000 cfs. Simulated DO concentrations at Station R1 are dominated by the assumed river inflow concentration. Simulated DO concentrations at Stations R3, R5, and R7 are very similar because the downstream flow distributes the oxygen demands to each of these stations. The DO at Station R5 is the lowest, reaching a minimum of about 4 mg/l at the end of July when the simulated inflow DO concentration is 5 mg/l. The monthly average DO concentrations at each measurement station for a net flow of 1,000 cfs are given in Table 9.

Summary of Effects of Flow on Dissolved Oxygen

The average flow past Stockton is estimated to be about 0 cfs during periods when the Vernalis flow is approximately 1,000 cfs. Increasing the net flow at Stockton with the use of an operable tidal gate at the head of Old River could have a dramatic effect on DO concentrations in the San Joaquin River between Stockton and Turner Cut (between Stations R3 and R7). Table 10 indicates, for example, that at a flow of 1,000 cfs the simulated monthly average DO concentrations for August would be increased to above 5 mg/l at Stations R1 to R4 but would remain slightly less than 5 mg/l at Stations R5 and R6. Simulated conditions in September would be improved at Stations R1 to R6, but the average monthly DO could not be increased to 6 mg/l at Stations R4 to R6. The increased flow would benefit upstream stations (those with the lowest DO) but would also slightly reduce DO concentrations at some downstream stations.

Figures 19 and 20 compare the simulated monthly average DO concentrations for August and September at each of the stations for constant assumed net river flows of 0 cfs, 500 cfs, and 1,000 cfs. The improvement in DO concentrations at Stations R1-R5 is quite substantial for a net flow of 500 cfs. With a net flow of 1,000 cfs, there is additional improvement in the DO concentrations at

Stations R2-R6. With a net flow of 1,000 cfs in August, the average simulated DO concentrations at all stations except R5 and R6 are greater than 5 mg/l with the 1996 RWCF discharge. In September, with a net flow of 1,000 cfs, the average simulated DO concentration is greater than 5 mg/l at all stations, but is less than 6 mg/l at Stations R4-R6.

Simulated Effects of Changes in Stockton RWCF Discharge Load on Dissolved Oxygen Concentration

To estimate the effects of reductions in Stockton RWCF discharges on DO concentrations, simulations were performed for the same three levels of assumed net river flows described above, but with no RWCF discharges. This provides an assessment of the total effect of RWCF discharge loads on San Joaquin River DO concentrations. The City is investigating several different levels of treatment as part of the RWCF expansion planning and NPDES permit renewal process with the CVRWQCB.

No RWCF Discharge and No Net River Flow

Figure 21 shows the simulated DO concentrations with the Stockton RWCF discharge eliminated and a net river flow of 0 cfs. Table 7 gives the monthly average DO concentrations and also gives the changes in monthly average DO achieved by this complete elimination of the discharge at a net river flow of 0 cfs. The simulated increases in DO are greatest at Stations R1-R6 during the winter months, when the discharge ammonia has a relatively large effect on river DO, and next greatest during August and September, when the simulated ammonia discharge is increasing. DO concentrations at Stations R2-R4 remain less than 5 mg/l for at least one month at each station. The estimated SOD rates are high enough to prevent the relatively weak reaeration process in the Deepwater Ship Channel from increasing DO concentrations to above 5 mg/l during these warm months without a net downstream flow.

No RWCF Discharge and 500 cfs of Net River Flow

Figure 22 shows the simulated DO concentrations with the Stockton RWCF discharge eliminated and a net river flow of 500 cfs. Table 8 gives the monthly average DO concentrations and also gives the changes in monthly average DO achieved by this complete elimination of the discharge at a net river flow of 500 cfs. The DO concentration at Station R1 is maintained by the river inflow. The simulated increase in DO concentration is greatest at Stations R3-R7 during the winter months, when the discharge ammonia has a relatively large effect on river DO, and next greatest during August and September, when the ammonia discharge is increasing from the levels of June and July. DO concentrations at Stations R3-R5 remain less than 5 mg/l for at least one month at each station.

No RWCF Discharge and 1,000 cfs of Net River Flow

Figure 23 shows the simulated DO concentrations with the Stockton RWCF discharge eliminated and a net river flow of 1,000 cfs. Table 9 gives the monthly average DO concentrations and also gives the changes in monthly average DO achieved by this complete elimination of the discharge at a net river flow of 1,000 cfs. The DO at Station R1 is maintained by the river inflow. The simulated increase in DO concentration is greatest at Stations R3-R7 during the winter months, when the discharge ammonia has a relatively large effect on river DO, and during August and September, when the ammonia discharge is increasing. The average DO concentrations are greater than 5 mg/l at all stations, but the simulated DO increase was less than 1 mg/l at each station in all months (Table 9).

Summary of Effects of Reduced RWCF Discharge on Dissolved Oxygen

This series of comparative simulations indicates that the DO objectives would not be achieved under a scenario in which the RWCF discharge is completely eliminated. The effects of eliminating the 1996 RWCF discharge on simulated DO concentrations are reduced as the assumed net flow past Stockton increases. The average increase in DO concentration is less than 0.5 mg/l with a flow of 1,000 cfs. The effects of possible reduced effluent limits would be less than the simulated effects of eliminating the current discharge.

Comparison of Tables 7 and 10 indicates that the simulated improvement in DO concentrations between Stations R3 and R7 (region of the 6-mg/l DO objective) is similar for increasing the flow from 0 cfs to 1,000 cfs with 1996 RWCF discharge and for eliminating the Stockton RWCF discharge with a flow of 0 cfs. Because increased flows can be achieved with use of an operable barrier at the head of Old River, while the elimination of the entire Stockton RWCF discharge is not feasible, the possible future management of flows near Stockton is a much more likely alternative for achieving the DO objectives.

Simulated Effects of River Aeration on Dissolved Oxygen Concentration

Given the difficulty of achieving the DO objectives even if extreme additional measures to reduce RWCF loads are undertaken, some consideration of river reaeration using bubble jets or oxygen diffusers is appropriate. Because most of the materials contributing to the SOD are from upstream sources, use of aeration devices to counteract this upstream load, in addition to control of upstream nonpoint-source contributions (i.e., best management practices [BMPs]), may be an acceptable DO management strategy for this portion of the San Joaquin River.

Figure 24 shows the effects of adding 4,500 lbs/day of oxygen to the Deepwater Ship Channel (at Station R3) during June-September with a flow of 1,000 cfs and with the 1996 Stockton RWCF effluent loads. If mixed uniformly in the river flow of 1,000 cfs, the DO concentration would be increased by 0.8 mg/l. The monthly simulated average DO concentrations are given for each station in Table 11. The DO improvement between Stations R3 and R7 is about 0.5 mg/l at a net flow of 1,000 cfs. This is sufficient to achieve the 5-mg/l DO objective in August and the 6-mg/l DO objective in September.

It may prove difficult to achieve this amount of reaeration increase because the maximum DO deficit (i.e., the reaeration potential) for a DO objective of 5 mg/l in August or 6 mg/l in September is only about 3 mg/l. To achieve an average increase of 0.6 mg/l in the river, about 20% of the flow (200 cfs) would have to be reaerated to saturated DO concentration. This is a relatively large flow for either side-stream (waterfall) or jet aeration devices. Nevertheless, this may be more economical and effective than other alternatives and should be investigated further. City consultants are currently conducting more detailed engineering evaluations of these issues.

Simulated Effects of Reduced Sediment Oxygen Demand on Dissolved Oxygen Concentration

Figure 25 shows the simulated effects of reducing the estimated SOD rate by 50% for a flow of 1,000 cfs and with the 1996 Stockton RWCF effluent loads. The monthly average DO concentrations at each measurement station are given in Table 12. The DO concentrations are increased by about 0.5-0.7 mg/l at Stations R3 to R7 by this assumed reduction in SOD. Reaeration is able to balance the reduced SOD with a smaller DO deficit, so the DO concentrations remain closer to saturation. The DO concentrations in September are raised to greater than 6 mg/l at all stations.

The improvement in DO concentrations with this assumed reduction in SOD is substantial. However, it may be difficult to control the SOD in the San Joaquin River. The SOD is maintained by organic particulates settling and by anaerobic chemical processes in the sediments. Therefore, reducing the VSS loading from the San Joaquin River would reduce the SOD. These comparisons indicate that the SOD is a major factor influencing DO concentrations, so there should be an effort to measure the SOD rates as well as the rate of accumulation of VSS materials. The practical ability to control sources of VSS in the San Joaquin River should also be further investigated.

RECOMMENDATIONS

There are several important factors controlling DO concentrations in the San Joaquin River in the vicinity of Stockton. The extensive historical measurements of water quality in the San Joaquin River, together with comparative evaluations of the Stockton water quality model results, provide a very effective planning and management tool for controlling the DO concentrations in the San Joaquin River. The specific assumptions used in these comparative evaluations of water quality management alternatives may not represent the selected solution, and a combination of approaches is recommended.

Several recommendations can be suggested as a result of this evaluation. Some of these suggested tasks will lead to a greater understanding of processes that control DO concentrations. Other suggestions will improve the adaptive management of water quality and fisheries in the lower San Joaquin River.

(1) Because fall migration of chinook salmon is unlikely when water temperatures are greater than 68°F (20°C), and because of the difficulty of maintaining DO concentrations of greater than 6 mg/l when water temperatures are greater than 68°F as a result of the reduced saturation concentration, the possibility of establishing a conditional 6-mg/l DO objective should be evaluated. It is important to understand the basis of the DO objectives so that the regulatory programs are appropriately focused.

(2) Use of an operable gate at the head of Old River should be evaluated as an effective method for providing control of the San Joaquin River flow and inflowing organic loads that have major effects on DO concentrations in the vicinity of Stockton. A corresponding flow objective at Stockton should also be evaluated.

(3) River aeration devices should be considered as one of the management alternatives for meeting the DO objective in this portion of the San Joaquin River because a major portion of the organic particulates (VSS) contributing to SOD come from upstream sources. The performance of the Corps jet bubbler device should be measured with a field experiment using propane as a gas tracer.

(4) Measurements should be made of the San Joaquin River water and Stockton RWCF effluent to compare long-term BOD and SOD effects from VSS loads contributed by the river and the RWCF effluent.

(5) Upstream controls of nonpoint sources of nutrients and organic loads (VSS) through BMPs and total maximum daily load (TMDL) allocations should be implemented as a long-term solution to achieving DO objectives in the San Joaquin River. Other measures discussed in these recommendations could also be incorporated into an overall TMDL program.

(6) Measurements of SOD in the San Joaquin River channel upstream and downstream of the RWCF discharge location should be obtained to confirm model estimates with direct field samples and laboratory measurements.

(7) The continuous monitoring of flow, salinity, temperature, DO, and pH in the San Joaquin River should be linked with measurements of nutrients, VSS, and chlorophyll (i.e., fluorescence) to determine the sources and timing of high organic loads so that the head of Old River barrier can be operated in an adaptive management framework.

CITATIONS

California Department of Water Resources and U.S. Bureau of Reclamation. 1996. Environmental impact report (EIR)/environmental impact statement (EIS): Interim South Delta Program. July. California Department of Water Resources, Sacramento, CA, and U.S. Bureau of Reclamation, Folsom, CA. Prepared by ENTRIX, Inc., Sacramento, CA.

__________. 1995. San Joaquin River management plan. February. Sacramento, CA.

California Regional Water Quality Control Board, Central Valley Region. 1995. Water quality control plan (basin plan), Central Valley Region, Sacramento River and San Joaquin River basins. Sacramento, CA.

California State Water Resources Control Board. 1995. Water quality control plan for the San Francisco Bay/Sacramento-San Joaquin Delta estuary. Draft. May. Sacramento, CA.

__________. 1997. Draft environmental impact report for implementation of the 1995 Bay/Delta water quality control plan. November. Sacramento, CA.

Chen, C. and W. Tsai. 1996. Effects of Bay-Delta operations on dissolved oxygen in the San Joaquin River. Systech Engineering. San Ramon, CA. Prepared for City of Stockton Municipal Utilities Department, Stockton, CA.

__________. 1997. Evaluation of alternatives to meet the dissolved oxygen objectives for the lower San Joaquin River. Systech Engineering. San Ramon, CA. Prepared for State Water Resources Control Board on behalf of the City of Stockton Municipal Utilities Department, Stockton, CA.

Civil Engineering. Chicago's waterfalls. Civil Engineering July 1994.

Hallock, R. J., R. F. Elwell, and D. H. Fry. 1970. Migrations of adult king salmon in the San Joaquin Delta as demonstrated by the use of sonic tags. California Department of Fish and Game Fish Bulletin 151.

Lifton, W. S. 1990. A review of proposed water temperature and dissolved oxygen objectives for the San Joaquin River. Exhibit WQCP-CVPWA 202 prepared for State Water Resources Control Board Bay-Delta 1990 Water Quality Control Plan hearings.

San Joaquin River Interest and Export Interests. 1996. Proposed agreement on San Joaquin River protection - expanding the consensus process.

D-041933

Schanz, R. and C. Chen. 1993. City of Stockton water quality model Volume I: model development and calibration. Philip Williams and Associates and Systech Engineering, San Francisco, CA. Prepared for City of Stockton, Stockton, CA.

Simpson M. R., and R. N. Oltmann 1992. Discharge-measurement system using an acoustic Doppler current profiler with applications to large rivers and estuaries. USGS Water-Supply Paper 2395.

U.S. Army Corps of Engineers. 1988. Dissolved oxygen study Stockton Deep Water Ship Channel. Office report. Sacramento District. Sacramento, CA.

Van Nieuwenhuyse, E. E., and J. R. Jones. 1996. Phosphorus-chlorophyll relationship in temperate streams and its variation with stream catchment area. Can. J. Fish. Aquat. Sci. 53: 99-105.

TABLES

Table 1. DWRSIM-Simulated San Joaquin River Flow (cfs) at Vernalis with 1995 WQCP Objectives (Run 472)

Exceedence	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
0%	12,445	13,555	21,502	24,863	36,538	41,113	27,030	26,214	36,449	13,590	1,917	6,500
10%	5,926	2,392	4,946	11,154	14,545	14,580	13,615	13,175	9,395	2,816	1,861	2,587
20%	4,237	2,108	3,058	6,039	9,503	8,734	6,740	6,049	5,633	1,909	1,825	1,958
30%	3,252	1,847	2,293	3,975	7,190	6,100	6,193	5,162	2,659	1,847	1,778	1,919
40%	2,333	1,727	1,877	2,506	5,281	4,388	5,340	5,162	2,141	1,736	1,726	1,827
50%	2,000	1,622	1,707	2,004	3,755	3,420	3,987	3,828	2,130	1,666	1,670	1,698
60%	2,000	1,482	1,495	1,684	2,676	2,797	3,987	3,538	1,751	1,569	1,616	1,615
70%	2,000	1,433	1,351	1,459	2,280	2,280	2,807	2,678	1,631	1,481	1,502	1,522
80%	1,841	1,391	1,280	1,209	1,845	1,911	2,420	1,985	1,498	1,410	1,428	1,432
90%	1,412	1,292	1,174	1,149	1,420	1,658	1,990	1,902	1,333	1,302	1,261	1,362
100%	1,274	1,188	1,071	982	975	1,234	1,990	1,871	1,240	1,136	1,109	1,275

D-041937

Table 2. Barrier at Head of Old River, Spring and Fall Closure Dates

	Spring				Fall			
	Installation		Removal		Installation		Removal	
Year	Start	Finish	Start	Finish	Start	Finish	Start	Finish
1963	None					- Barge sunk in Old River during Fall -		
1964	None					September 16		November 15
1965	None				None			
1966	None				None			
1967	None				None			
1968	None					October 4		November 17
1969	None				None			
1970	None					October 6		November 14
1971	None					September 30		November 12
1972	None					September 29		November 10
1973	None					October 5		November 15
1974	None					September 18		November 9
1975	None					September 26		November 4
1976	None					November 1		November 23
1977	None					October 27		December 5
1978	None				None			
1979	None					October 1		November 29
1980	None				None			
1981	None					October 15		November 25
1982	None				None			
1983	None				None			
1984	None					September 8		October 19
1985	None				None			
1986	None				None			
1987	None				September 9	September 11		November 28
1988	None				September 22	September 28		December 2
1989	None				September 27	September 29		November 30
1990	None				September 10	September 11		November 27
1991	None				September 9	September 13	November 22	November 27
1992	April 15	May 1		May 15	September 8	September 11	November 30	December 4
1993	None				November 8	November 11	December 3	December 7
1994	April 21	April 23	May 18	May 20	September 6	September 8	November 28	November 30
1995	None				None			
1996	May 6	May 11	May 16	May 18	September 30	October 3	November 18	November 22
1997	April 9	April 16	May 15	May 19	None			

None = not closed

Source: Data from Simon Kwan, DWR, Delta Planning Division

Table 3. Assumed San Joaquin River Geometry for the Stockton DO Model

Node	Downstream Link	River Location	Water Quality Station	Area at 0 feet msl (acres)	Area at 4 feet msl (acres)	Depth at 0 feet msl (Feet)	Depth at 4 feet msl (Feet)	Volume at 0 feet msl (AF)	Volume at 4 feet msl (AF)	Width at 0 feet msl (feet)	Conveyance at 0 feet msl (square feet)	Length (miles)	Sediment Oxygen Demand (g-O2/M2/DAY)
1	1	Old River	R0A	15	16	4	8	65	126	148	651	0.8	2.3
97	100			15	16	5	8	68	129	148	710	0.8	2.4
2	2			16	18	5	8	80	145	151	800	0.9	2.3
98	101			17	19	6	9	96	166	151	890	0.9	2.4
3	3			19	21	6	9	119	197	158	1,153	1.1	2.4
4	4			22	24	7	10	156	245	160	1,104	1.2	2.4
5	5		R1	25	27	7	10	182	281	183	1,427	1.2	2.6
6	6			26	29	9	12	236	341	167	1,703	1.3	2.8
7	7			23	25	10	13	234	327	166	1,709	1.0	2.9
8	8			22	24	9	12	206	295	173	1,470	1.1	3.0
9	24			28	36	8	10	229	346	215	2,085	0.7	3.1
25	25		R2	22	23	11	14	228	316	229	2,565	0.9	3.1
26	26	RWCF		23	25	11	14	260	353	267	2,990	0.7	3.1
27	30			31	37	10	12	298	424	226	2,802	0.9	3.1
31 to 33	31	Turning Basin		126	130	23	26	2,876	3,388	469	15,195	2.0	1.7
30	40	Ship Channel	R3	59	62	27	30	1,599	1,838	512	14,234	0.6	1.7
39	41			38	39	28	31	1,048	1,201	514	13,980	0.6	1.7
40	45		R4	65	66	23	26	1,457	1,716	571	15,074	1.0	1.7
44	60	Calaveras	R5	81	88	21	23	1,724	2,051	530	12,879	1.0	1.6
59	61			57	59	24	27	1,383	1,612	455	11,056	1.0	1.6
60	62		R6	61	63	24	28	1,479	1,722	550	13,475	1.0	1.5
61	92	Fourteen Mile		93	96	20	23	1,864	2,238	656	15,809	0.9	1.4
91	93			84	86	23	26	1,909	2,248	735	15,876	1.1	1.3
92	96	Turner Cut	R7	189	196	18	21	3,363	4,122	1,317	22,965	1.6	1.3
95	99			159	164	18	21	2,800	3,439	869	17,640	0.8	1.3
96	Boundary	Columbia Cut	R8	83	85	20	24	1,687	2,020	850	17,255	0.8	1.3
				Total	Total	Average	Average	Total	Total	Average	Average	Total	Average
		Old River to Turning Basin		304	341	8	11	2,458	3,692	178	7,551	13.6	2.8
		Turning Basin to Turner Cut		727	756	22	25	15,827	18,750	711	92,311	8.7	1.5

Table 4. Field Data for the San Joaquin River

Program	Data	Frequency and Source
DWR Continuous Monitoring Program, 1984-present	DO, temperature, pH, EC at Mossdale and Stockton Deepwater Ship Channel	Hourly values available from IEP web page: http://www.iep.water.ca.gov
D1485 Discrete Water Quality Sampling Program, 1975-present	DO, temperature, nutrients, suspended solids, turbidity, etc., at four stations	Sampling is usually monthly. Data available from IEP web page.
D1485 Longitudinal DO Sampling Program, 1969-present	Surface and bottom temperature and DO at 26 stations (currently 14 stations)	Discrete sampling in conjunction with barrier closure at head of Old River; see IEP web page.
Stockton RWCF Effluent Monitoring Program 1986-present	Flow, BOD, TSS, VSS, TDS, EC, pH, temperature, TOC, TP , nitrogen, turbidity	Daily grab samples whenever effluent is discharged to river. Available from Stockton RWCF office.
Stockton RWCF River Water Quality Monitoring Program 1986-present	DO, temperature, pH, TDS, EC, nitrogen, TSS, turbidity secchi depth at eight stations	Daily/periodic grab samples. Available from Stockton RWCF office.
Stockton RWCF NPDES river water quality monitoring 1990-1991	Same variables as for above program, plus BOD and chlorophyll	Daily/periodic grab samples.
U.S. Geological Survey, NASQAN Monitoring Station, San Joaquin River near Vernalis, 1950s-1960s to present (depending on analyte)	Flow, temperature, EC, pH, suspended sediment, several forms of nitrogen, total and dissolved phosphorus, Ca, Mg, Na, K, phytoplankton density (1974-81)	Daily temperature and sediment sampling, monthly water quality (depth integrated samples). Data available from STORET.

Table 5. Monthly Average San Joaquin River Flow, Concentrations, and Loads at Mossdale for 1987-1995

Table 5a

San Joaquin River Flow near Vernalis (cfs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	2,305	2,136	3,415	2,867	2,178	1,990	1,632	1,627	1,597	1,370	1,548	1,278
1988	1,483	1,389	2,241	2,146	1,781	1,711	1,357	1,557	1,452	1,127	1,274	1,372
1989	1,255	1,234	2,023	1,915	1,949	1,583	1,284	1,169	1,353	1,401	1,404	1,381
1990	1,242	1,365	1,760	1,309	1,279	1,116	1,009	1,033	876	993	1,115	918
1991	816	758	1,779	1,168	1,049	568	594	537	574	789	1,084	895
1992	959	2,091	1,470	1,418	892	481	447	483	635	849	956	982
1993	4,120	3,035	2,702	3,421	3,610	2,341	1,510	1,998	2,771	3,041	1,759	1,628
1994	1,773	1,987	2,206	1,863	1,973	1,109	1,135	867	869	1,370	1,288	1,295
1995	4,599	6,559	14,612	19,933	22,187	14,101	9,881	3,925	4,734			
Average:	2,061	2,284	3,579	4,005	4,100	2,778	2,094	1,466	1,651	1,367	1,304	1,219

Estimated San Joaquin River Flow at Stockton (cfs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	632	541	1,231	935	563	462	268	266	1;125	1,370	1,458	77
1988	188	137	597	546	349	311	120	228	288	1,127	1,274	208
1989	65	53	480	421	440	242	80	18	207	1,401	1,404	133
1990	58	124	338	94	78	(10)	(68)	(55)	529	993	1,003	(117)
1991	(172)	(204)	348	18	(47)	(306)	(292)	(323)	231	789	758	(130)
1992	(95)	516	181	153	420	(354)	(372)	(352)	338	849	922	(83)
1993	1,612	1,026	846	1,234	1,336	651	202	466	883	1,029	1,267	355
1994	344	460	578	896	1,317	(14)	0	(145)	638	127	82	86
1995	1,871	2,929	7,277	10,151	11,368	7,002	4,723	1,506	1,944			
Average:	500	620	1,319	1,605	1,758	887	518	179	687	960	1,021	66

Stockton flow (Qstock) estimated as: Qstock = -613 + 0.54 (Qvern), where Qstock is net flow measured by USGS UVM station (1995-1996) and Qvern is measured flow at Vernalis (s=272, R^2=0.98, n=299). Qstock assumed equal to Qvern when barrier at head of Old River was closed.

Source: California Department of Water Resources.

D-041941

Table 5b

Monthly Average Flow-weighted Mean Volatile Suspended Solids Concentration (mg/l), San Joaquin River at Mossdale												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	3.0	6.0	2.0	5.0	8.0	3.5	13.3	11.5	7.5	9.0	5.0	7.0
1988	4.0	6.0	3.0	3.5	3.3	11.0	11.5	9.4	5.0	7.5	4.0	4.0
1989	3.0	4.0	4.0	6.7	7.0	8.5	10.0	10.0	8.5	5.0	5.0	2.0
1990	6.0	10.0	5.0	6.9	15.1	17.8	11.0	7.1	9.5	5.0	3.0	2.0
1991	4.0	4.0	7.9	8.0	9.2	21.5	15.6	17.6	19.5	15.6	4.0	2.0
1992	2.0	7.0	8.5	6.4	8.0	16.5	23.5	16.4	10.0	5.2	4.0	1.0
1993	41.0	18.0	5.0	7.0	5.0	4.0	6.8	9.0	8.0	4.0	2.0	1.0
1994												
1995												
Average:	9.0	7.9	5.1	6.2	7.9	11.8	13.1	11.6	9.7	7.3	3.9	2.7

Data not available for 1994-95

Monthly Average Volatile Suspended Solids Load (lbs/day), San Joaquin River Downstream of Old River Flow Split (Load defined as flow-weighted mean concentration at Mossdale times average estimated flow at Stockton)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	10,235	17,512	13,293	25,250	24,322	8,724	19,320	16,473	45,579	66,198	39,456	2,918
1988	4,052	4,439	9,670	10,196	6,161	18,400	7,420	11,573	7,784	45,749	27,525	4,488
1989	1,050	1,151	10,357	15,243	16,621	11,112	4,345	994	9,474	37,903	37,916	1,435
1990	1,866	6,712	9,115	3,523	6,360	0	0	0	27,023	26,816	16,253	0
1991	0	0	14,810	770	0	0	0	0	24,310	66,338	16,366	0
1992	0	19,505	8,329	5,268	18,135	0	0	0	18,232	23,602	19,909	0
1993	356,853	99,737	22,847	46,653	36,083	14,064	7,403	22,652	38,159	22,224	13,686	1,914
1994												
1995												
Average:	53,437	21,294	12,632	15,272	15,383	7,471	5,498	7,385	24,366	41,261	24,444	1,537

Note: Load equated to zero for reverse flows at Stockton (see Table 5a)

Source: California Department of Water Resources.

D-041942

Table 5c

Monthly Average Flow-weighted Mean Chlorophyll Concentration (ug/l), San Joaquin River at Mossdale

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	6	10	12	26	44	68	73	49	55	30	9	15
1988	13	19	19	25	65	49	73	83	46	84	29	14
1989	11	18	24	24	30	45	77	52	38	18	9	4
1990	16	22	14	42	45	167	94	56	49	20	2	4
1991	17	12	29	54	95	337	204	149	311	218	28	19
1992	9	17	34	65	101	313	421	390	185	73	21	8
1993	24	13	52	38	16	35	91	40	18	14	9	4
1994												
1995												
Average:	14	16	26	39	57	145	148	117	100	65	15	10

Data not available for 1994-95

Monthly Average Chlorophyll Load (lbs/day), San Joaquin River Downstream of Old River Flow Split
(Load defined as flow-weighted mean concentration at Mossdale times average estimated flow at Stockton)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	20	29	79	129	134	171	106	70	334	220	73	6
1988	13	14	63	73	122	83	47	102	72	511	198	16
1989	4	5	61	55	70	58	34	5	42	138	65	3
1990	5	15	26	21	19	0	0	0	140	110	12	0
1991	0	0	55	5	0	0	0	0	388	928	113	0
1992	0	48	33	53	230	0	0	0	338	333	104	0
1993	210	71	239	251	116	124	100	101	87	78	59	8
1994												
1995												
Average:	36	26	79	84	99	62	41	40	200	331	89	5

Note: Load equated to zero for reverse flows at Stockton (see Table 5a)

Source: California Department of Water Resources.

Table 5d

Monthly Average Flow-weighted Mean Biochemical Oxygen Demand (mg/L), San Joaquin River at Mossdale BOD estimated from chlorophyll concentration (see Figure 17)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	1.4	1.8	2.0	2.8	3.7	4.6	4.7	3.9	4.1	3.1	1.7	2.2
1988	2.0	2.4	2.5	2.8	4.4	3.9	4.7	5.0	3.8	5.0	3.0	2.1
1989	1.9	2.4	2.7	2.8	3.0	3.7	4.8	4.0	3.4	2.4	1.7	1.1
1990	2.3	2.6	2.1	3.6	3.7	7.0	5.3	4.1	3.9	2.6	0.9	1.2
1991	2.4	1.9	3.0	4.1	5.3	9.8	7.7	6.6	9.4	7.9	2.9	2.4
1992	1.7	2.4	3.2	4.4	5.5	9.4	10.9	10.5	7.3	4.7	2.6	1.6
1993	2.8	2.0	4.0	3.4	2.3	3.3	5.2	3.5	2.4	2.1	1.7	1.2
1994												
1995												
Average:	2.1	2.2	2.8	3.4	4.0	6.0	6.2	5.4	4.9	4.0	2.1	1.7

Data not available for 1994-95

Monthly Average Biochemical Oxygen Demand Load (lbs/day), San Joaquin River Downstream of Old River Flow Split (Load defined as flow-weighted mean concentration at Mossdale times average estimated flow at Stockton)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	4801	5225	13067	14341	11198	11348	6813	5534	24905	22596	13755	929
1988	2047	1811	8016	8214	8368	6542	3035	6156	5883	30571	20653	2397
1989	653	691	7066	6283	7228	4850	2094	396	3833	18272	12699	801
1990	708	1759	3918	1825	1572	0	0	0	11067	13686	4706	0
1991	0	0	5669	389	0	0	0	0	11746	33800	12052	0
1992	0	6572	3157	3655	12454	0	0	0	13403	21487	12796	0
1993	24020	11307	18289	22790	16418	11633	5705	8875	11514	11822	11498	2219
1994												
1995												
Average:	4604	3909	8455	8214	8177	4911	2521	2994	11765	21748	12594	907

Note: Load equated to zero for reverse flows at Stockton (see Table 5a)

Source: California Department of Water Resources.

D-041944

D-041945

Table 5e

Monthly Average Flow-weighted Mean Ammonia-N Concentration (mg/l), San Joaquin River at Mossdale												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	0.24	0.24	0.11	0.02	0.00	0.00	0.01	0.01	0.01	0.02	0.06	0.08
1988	0.24	0.08	0.03	0.03	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.09
1989	0.26	0.33	0.02	0.03	0.03	0.01	0.10	0.02	0.03	0.03	0.05	0.07
1990	0.82	0.35	0.04	0.02	0.05	0.01	0.01	0.01	0.03	0.01	0.01	0.07
1991	0.11	0.06	0.41	0.08	0.01	0.01	0.01	0.16	0.02	0.02	0.06	0.06
1992	0.22	0.15	0.03	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.04	0.04
1993	0.87	0.95	0.01	0.02	0.04	0.01	0.01	0.02	0.02	0.02	0.12	0.06
1994												
1995												
Average:	0.39	0.31	0.09	0.03	0.02	0.01	0.02	0.03	0.02	0.02	0.05	0.07

Data not available for 1994-95

Monthly Average Ammonia-N Load (lbs/day), San Joaquin River Downstream of Old River Flow Split (Load defined as flow-weighted mean concentration at Mossdale times average estimated flow at Stockton)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	819	700	731	101	0	0	14	14	61	148	473	33
1988	243	59	97	88	19	0	13	0	16	0	69	101
1989	91	95	52	68	71	13	43	2	34	227	379	50
1990	255	235	73	10	21	0	0	0	86	54	54	0
1991	0	0	770	8	0	0	0	0	25	85	245	0
1992	0	418	29	8	23	0	0	0	18	46	199	0
1993	7572	5264	46	133	289	35	11	50	95	111	821	115
1994												
1995												
Average:	1283	967	257	60	60	7	12	10	48	96	320	43

Note: Load equated to zero for reverse flows at Stockton (see Table 5a)

Source: California Department of Water Resources.

D-041945

Table 5f

Monthly Average Daily Mean Water Temperature (°C), Stockton Ship Channel at Burns Cutoff												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	8.4	10.5	14.9	19.0	22.4	23.9	24.8	24.8	23.5	21.1	15.5	10.4
1988	8.3	11.2	14.6	18.2	20.0	23.1	25.9	25.4	23.7	20.5	14.9	9.8
1989	7.2	8.9	14.3	19.8	21.1	23.4	25.3	24.8	20.2	20.0	14.2	10.4
1990	8.7	9.7	13.8	18.8	20.9	23.2	25.7	25.5	24.0	20.7	14.2	10.4
1991	8.6	11.4	13.0	15.8	19.3	22.5	25.1	25.1	24.3	22.3	14.7	9.8
1992	8.7	11.9	16.2	19.7	23.3	24.5	25.4	26.2	24.0	21.5	14.3	9.8
1993	9.0	11.6	16.1	16.8	19.9	22.5	25.1	25.5	23.6	19.4	14.6	10.3
1994	9.4	10.7	16.0	18.3	20.4	23.8	26.2	25.9	24.0	19.8	12.9	9.7
1995	10.5	12.4	13.8	15.2	18.3	19.8	23.4	24.7	22.5			
Average:	8.8	10.9	14.7	18.0	20.6	23.0	25.2	25.3	23.3	20.7	14.4	10.1

Monthly Average Daily Mean Dissolved Oxygen Saturation (mg/l), Stockton Ship Channel at Burns Cutoff												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	11.8	11.2	10.2	9.4	8.8	8.5	8.4	8.4	8.6	9.0	10.1	11.2
1988	11.8	11.0	10.2	9.5	9.2	8.7	8.2	8.3	8.6	9.1	10.2	11.4
1989	12.1	11.6	10.3	9.2	9.0	8.6	8.3	8.4	9.1	9.2	10.3	11.2
1990	11.7	11.4	10.4	9.4	9.0	8.6	8.3	8.3	8.5	9.1	10.3	11.2
1991	11.7	11.0	10.6	10.0	9.3	8.8	8.3	8.3	8.5	8.8	10.2	11.4
1992	11.7	10.9	9.9	9.2	8.6	8.4	8.3	8.2	8.5	8.9	10.3	11.4
1993	11.6	10.9	9.9	9.8	9.2	8.8	8.3	8.3	8.6	9.3	10.2	11.3
1994	11.5	11.2	10.0	9.5	9.1	8.5	8.2	8.2	8.5	9.2	10.6	11.4
1995	11.2	10.8	10.4	10.1	9.5	9.2	8.6	8.4	8.8			
Average:	11.7	11.1	10.2	9.6	9.1	8.7	8.3	8.3	8.6	9.1	10.3	11.3

Source: California Department of Water Resources.

D-041946

Table 6. Monthly Average Effluent Discharge, Concentrations, and Loads for the Stockton RWCF for 1987-1995

Table 6a

Effluent Discharge (cfs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	33.3	46.8	38.0	35.8	32.8	31.4	40.8	43.6	44.1	33.4	50.6	29.3
1988	38.0	33.5	33.5	40.8	40.9	32.3	24.7	43.9	44.5	31.6	50.4	30.2
1989	40.7	39.1	34.9	34.3	31.0	33.4	50.5	41.9	44.3	36.6	46.4	36.1
1990	39.6	34.9	35.0	31.6	34.7	33.0	42.3	44.9	41.5	25.2	43.9	44.1
1991	42.4	24.4	44.2	39.0	16.9	30.7	35.2	34.1	30.5	40.7	38.6	24.8
1992	48.1	25.7	48.3	33.4	26.8	33.7	29.0	41.0	38.2	28.2	37.5	34.5
1993	50.2	36.1	40.2	36.4	34.4	22.3	34.9	41.5	36.7	29.2	30.3	33.8
1994	34.8	39.5	25.6	28.8	35.5	27.4	38.2	30.3	41.7	34.4	26.0	32.5
1995	50.1	35.1	54.1	34.8	32.1	25.8	30.4	49.3	31.0			
Average:	41.9	35.0	39.3	35.0	31.7	30.0	36.2	41.2	39.2	32.4	40.4	33.1

San Joaquin River Flow at Stockton (cfs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	632	541	1,231	935	563	462	268	266	1,125	1,370	1,458	77
1988	188	137	597	546	349	311	120	228	288	1,127	1,274	208
1989	65	53	480	421	440	242	80	18	207	1,401	1,404	133
1990	58	124	338	94	78	(10)	(68)	(55)	529	993	1,003	(117)
1991	(172)	(204)	348	18	(47)	(306)	(292)	(323)	231	789	758	(130)
1992	(95)	516	181	153	420	(354)	(372)	(352)	338	849	922	(83)
1993	1,612	1,026	846	1,234	1,336	651	202	466	883	1,029	1,267	355
1994	344	460	578	896	1,317	(14)	0	(145)	638	127	82	86
1995	1,871	2,929	7,277	10,151	11,368	7,002	4,723	1,506	1,944			
Average:	500	620	1,319	1,605	1,758	887	518	179	687	960	1,021	66

Source: City of Stockton.

Table 6b

Effluent Biochemical Oxygen Demand (mg/L)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	16	21	17	17	7	7	5	3	15	14	21	17
1988	16	12	15	13	8	7	6	5	9	11	19	17
1989	17	16	15	6	6	4	4	7	7	10	11	14
1990	14	17	18	5	5	7	6	9	8	8	9	13
1991	15	17	14	9	7	6	6	6	9	8	17	15
1992	15	14	4	7	6	5	6	6	6	7	11	11
1993	12	11	13	10	8	10	5	7	8	6	11	19
1994	17	19	20	12	12	7	4	5	6	4	6	9
1995	10	14	10	6	4	6	5	9	12			
Average:	14	16	14	9	7	6	5	6	9	9	13	14

Effluent Biochemical Oxygen Demand Load (lbs/day)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	2,849	5,191	3,463	3,292	1,200	1,133	1,155	799	3,554	2,484	5,859	2,643
1988	3,193	2,172	2,712	2,884	1,772	1,176	793	1,199	2,123	1,915	5,188	2,729
1989	3,648	3,426	2,869	1,192	1,051	792	1,170	1,670	1,681	2,021	2,690	2,714
1990	2,936	3,251	3,436	929	947	1,201	1,422	2,138	1,897	1,152	2,206	3,083
1991	3,465	2,293	3,448	1,826	648	966	1,085	1,107	1,437	1,778	3,514	2,022
1992	3,840	1,997	953	1,173	926	835	1,004	1,306	1,230	1,066	2,258	2,049
1993	3,130	2,064	2,810	1,908	1,536	1,189	869	1,465	1,682	1,010	1,797	3,502
1994	3,106	3,952	2,825	1,808	2,205	1,038	873	816	1,381	796	862	1,551
1995	2,587	2,634	3,025	1,141	669	772	776	2,436	1,928			
Average:	3,195	2,998	2,838	1,795	1,217	1,012	1,017	1,437	1,879	1,528	3,047	2,536

Source: City of Stockton.

Table 6c

Effluent Ammonia-N Concentration (mg/L)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	8.7	9.5	5.6	3.9	2.1	4.6	0.6	0.1	13.3	17.9	17.5	11.8
1988	11.8	14.6	5.1	3.0	0.1	0.1	0.1	2.4	13.2	20.3	23.2	16.9
1989	14.9	14.5	7.0	0.4	1.9	0.1	0.1	4.8	13.5	14.3	19.1	17.6
1990	18.3	18.2	15.2	0.1	0.2	0.3	0.6	3.5	3.4	4.2	0.8	6.3
1991	19.0	19.1	15.1	12.8	10.9	0.2	1.2	6.0	13.4	19.9	23.3	24.7
1992	23.5	24.5	20.4	11.4	0.5	3.1	4.1	13.5	20.7	21.4	23.0	20.3
1993	18.8	15.8	15.3	3.8	2.0	2.5	2.9	8.9	17.4	20.9	20.4	21.2
1994	22.4	19.9	17.5	7.3	4.1	3.5	3.5	5.1	5.5	9.8	0.2	1.5
1995	11.7	11.9	5.0	0.9	0.1	0.1	0.2	5.6	11.8			
Average:	16.6	16.5	11.8	4.8	2.4	1.6	1.5	5.6	12.5	16.1	16.0	15.0

Effluent Ammonia-N Load (lbs/day)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	1,571	2,403	1,152	746	370	776	130	27	3,158	3,234	4,776	1,870
1988	2,434	2,638	921	653	22	17	13	580	3,176	3,460	6,324	2,764
1989	3,273	3,072	1,313	77	320	25	27	1,096	3,233	2,835	4,792	3,420
1990	3,919	3,440	2,882	17	45	53	134	842	766	566	196	1,510
1991	4,349	2,519	3,598	2,693	992	31	227	1,110	2,213	4,376	4,860	3,297
1992	6,108	3,401	5,328	2,063	65	565	646	2,996	4,275	3,246	4,663	3,775
1993	5,097	3,082	3,329	748	365	302	546	1,987	3,450	3,301	3,346	3,858
1994	4,215	4,248	2,421	1,130	794	525	728	842	1,235	1,825	28	267
1995	3,155	2,248	1,458	166	20	16	25	1,493	1,971			
Average:	3,791	3,006	2,489	921	333	257	275	1,219	2,609	2,855	3,623	2,595

Source: City of Stockton.

D—041949

Table 6d

Effluent Ammonia-N Oxygen Demand (mg/L)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	39.3	42.8	25.2	17.3	9.4	20.6	2.6	0.5	59.7	80.7	78.7	53.2
1988	53.3	65.7	22.9	13.3	0.4	0.4	0.4	11.0	59.5	91.2	104.6	76.2
1989	67.0	65.5	31.3	1.9	8.6	0.6	0.4	21.8	60.8	64.6	86.1	79.0
1990	82.5	82.1	68.5	0.4	1.1	1.3	2.6	15.6	15.4	18.7	3.7	28.6
1991	85.5	86.0	67.8	57.5	48.9	0.8	5.4	27.2	60.4	89.6	105.0	111.0
1992	105.7	110.3	92.0	51.5	2.0	14.0	18.6	60.9	93.3	96.1	103.7	91.3
1993	84.6	71.1	69.0	17.1	8.8	11.3	13.0	39.9	78.3	94.2	91.9	95.3
1994	100.9	89.7	78.7	32.7	18.6	16.0	15.9	23.2	24.7	44.2	0.9	6.9
1995	52.5	53.4	22.5	4.0	0.5	0.5	0.7	25.2	53.1			
Average:	74.6	74.1	53.1	21.8	10.9	7.3	6.6	25.0	56.1	72.4	71.8	67.7

Effluent Nitrogenous Oxygen Demand Load (lbs/day)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	7,070	10,815	5,182	3,358	1,666	3,493	583	121	14,210	14,555	21,492	8,417
1988	10,951	11,871	4,147	2,937	99	78	60	2,611	14,292	15,569	28,460	12,437
1989	14,729	13,825	5,908	348	1,438	114	123	4,934	14,549	12,757	21,565	15,392
1990	17,636	15,482	12,970	77	201	240	605	3,788	3,448	2,547	881	6,795
1991	19,569	11,336	16,193	12,119	4,464	141	1,023	4,997	9,960	19,694	21,872	14,835
1992	27,484	15,305	23,977	9,283	294	2,543	2,907	13,483	19,238	14,605	20,986	16,986
1993	22,938	13,870	14,981	3,365	1,643	1,361	2,459	8,944	15,524	14,853	15,059	17,361
1994	18,967	19,117	10,896	5,083	3,572	2,364	3,274	3,789	5,557	8,211	127	1,203
1995	14,198	10,117	6,560	745	92	71	112	6,719	8,870			
Average:	17,060	13,527	11,202	4,146	1,497	1,156	1,238	5,487	11,739	12,849	16,305	11,678

Source: City of Stockton.

D-041951

Table 6e

Effluent Volatile Suspended Solids (mg/L)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	17.4	25.1	26.4	24.0	6.8	9.4	13.7	8.6	10.7	7.6	23.3	25.3
1988	14.7	6.7	21.6	21.8	20.5	15.6	15.7	8.1	6.9	5.3	12.7	27.0
1989	25.8	18.0	17.2	17.9	17.0	19.9	7.8	10.7	7.3	8.5	19.1	19.8
1990	17.9	20.3	25.8	20.1	20.1	13.9	9.1	6.5	5.6	5.2	24.5	22.7
1991	15.0	17.3	26.4	17.8	11.4	13.4	8.1	8.3	7.7	6.8	22.3	24.5
1992	23.0	16.4	8.0	13.9	20.3	6.2	9.2	7.4	7.0	7.4	23.0	26.3
1993	21.4	16.4	24.7	21.3	16.6	20.1	5.2	7.4	6.4	6.7	20.1	21.1
1994	12.8	18.2	20.7	20.4	17.8	13.2	6.8	6.0	5.6	6.1	15.5	
1995												
Average:	18.5	17.3	21.3	19.6	16.3	14.0	9.4	7.9	7.1	6.7	20.1	23.8

Effluent Volatile Suspended Solids Load (lbs/day)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	3,122	6,338	5,422	4,641	1,208	1,601	3,006	2,019	2,554	1,372	6,368	4,000
1988	3,026	1,202	3,897	4,800	4,529	2,714	2,096	1,928	1,650	897	3,461	4,403
1989	5,671	3,806	3,235	3,307	2,835	3,584	2,111	2,429	1,737	1,670	4,792	3,860
1990	3,817	3,836	4,874	3,431	3,764	2,472	2,081	1,570	1,249	702	5,809	5,409
1991	3,427	2,282	6,297	3,752	1,040	2,223	1,537	1,521	1,266	1,486	4,637	3,274
1992	5,965	2,279	2,082	2,502	2,948	1,125	1,443	1,629	1,444	1,123	4,650	4,896
1993	5,789	3,206	5,357	4,189	3,084	2,417	973	1,655	1,276	1,063	3,297	3,840
1994	2,407	3,871	2,865	3,176	3,420	1,960	1,406	974	1,253	1,137	2,166	
1995												
Average:	4,153	3,352	4,254	3,725	2,854	2,262	1,832	1,716	1,554	1,181	4,397	4,240

Source: City of Stockton.

D-041951

Table 7. Stockton DO Model Results for Net Stockton Flow of 0 cfs:
1996 Discharge versus No Discharge

Monthly Average DO for 1996 Discharge with a Net Flow of 0 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	6.4	5.8	5.7	6.0	6.3	6.9	7.8	8.0
Nov	8.9	6.7	5.3	4.3	4.6	5.1	6.1	7.7	8.1
Dec	9.3	7.7	6.4	5.2	5.4	5.8	6.6	8.1	8.5
Jan	9.6	8.3	6.9	5.7	5.9	6.3	7.1	8.5	8.8
Feb	9.4	7.2	5.5	4.3	4.7	5.2	6.4	8.3	8.7
Mar	9.5	7.1	5.6	4.3	4.8	5.2	6.4	8.2	8.6
Apr	8.5	6.9	5.9	5.2	5.5	5.9	6.9	8.1	8.3
May	8.2	6.4	5.9	5.5	5.8	6.1	6.8	7.7	8.0
Jun	8.2	5.6	5.3	5.0	5.3	5.6	6.3	7.1	7.4
Jul	7.7	5.0	4.6	4.4	4.7	5.0	5.7	6.6	6.8
Aug	7.8	4.6	3.7	3.3	3.7	4.2	5.1	6.3	6.7
Sep	8.5	4.8	3.1	2.3	2.8	3.4	4.7	6.5	7.0

Monthly Average DO for No Discharge with a Net Flow of 0 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	6.9	6.7	6.7	6.8	7.0	7.3	7.9	8.1
Nov	8.9	7.6	7.2	6.8	6.9	7.1	7.5	8.2	8.3
Dec	9.3	8.6	8.0	7.5	7.6	7.8	8.1	8.7	8.8
Jan	9.6	9.4	8.9	8.4	8.4	8.5	8.8	9.1	9.2
Feb	9.4	8.8	8.6	8.4	8.5	8.6	8.8	9.1	9.2
Mar	9.5	8.4	8.3	8.1	8.3	8.4	8.7	9.0	9.0
Apr	8.5	7.5	7.3	7.2	7.4	7.6	8.0	8.5	8.5
May	8.2	6.6	6.3	6.2	6.4	6.6	7.2	7.9	8.0
Jun	8.2	5.7	5.5	5.4	5.6	5.9	6.5	7.2	7.4
Jul	7.7	5.2	4.9	4.8	5.1	5.3	5.9	6.6	6.8
Aug	7.8	5.2	4.8	4.5	4.8	5.1	5.7	6.5	6.7
Sep	8.5	5.9	5.3	5.0	5.2	5.5	6.1	6.9	7.2

Monthly Average DO Change for No Discharge with a Net Flow of 0 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	0.0	0.5	0.9	1.0	0.8	0.7	0.4	0.1	0.1
Nov	0.0	1.0	1.9	2.5	2.3	2.1	1.5	0.5	0.3
Dec	0.0	0.9	1.6	2.3	2.2	2.0	1.5	0.5	0.3
Jan	0.0	1.1	2.0	2.7	2.5	2.3	1.7	0.6	0.3
Feb	0.0	1.6	3.1	4.1	3.8	3.4	2.5	0.9	0.5
Mar	0.0	1.4	2.7	3.8	3.5	3.1	2.3	0.8	0.4
Apr	0.0	0.6	1.4	2.0	1.9	1.7	1.2	0.4	0.2
May	0.0	0.2	0.4	0.7	0.6	0.6	0.4	0.1	0.1
Jun	0.0	0.1	0.2	0.3	0.3	0.3	0.2	0.1	0.0
Jul	0.0	0.1	0.3	0.4	0.3	0.3	0.2	0.1	0.0
Aug	0.0	0.5	1.0	1.2	1.0	0.9	0.6	0.1	0.1
Sep	0.0	1.1	2.3	2.7	2.4	2.1	1.4	0.4	0.2

Table 8. Stockton DO Model Results for Net Stockton Flow of 500 cfs:
1996 Discharge versus No Discharge

Monthly Average DO for 1996 Discharge with a Net Flow of 500 cfs									
	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.2	7.5	6.2	6.0	6.0	6.3	7.3	7.7
Nov	8.9	8.7	8.3	6.4	6.0	6.0	6.1	7.1	7.6
Dec	9.3	9.2	9.1	7.6	7.2	7.2	7.2	7.9	8.3
Jan	9.6	9.6	9.4	8.1	7.7	7.7	7.7	8.4	8.7
Feb	9.4	9.4	9.2	7.5	7.1	7.1	7.2	8.1	8.5
Mar	9.5	9.3	8.9	7.3	7.1	7.0	7.1	8.0	8.4
Apr	8.5	8.5	8.1	7.0	6.8	6.8	7.0	7.8	8.1
May	8.2	8.0	7.5	6.5	6.4	6.4	6.6	7.4	7.7
Jun	8.2	7.6	6.8	5.9	5.8	5.8	6.1	6.9	7.2
Jul	7.7	6.6	5.6	4.8	4.8	4.9	5.3	6.2	6.5
Aug	7.8	7.0	5.9	4.1	4.0	4.1	4.5	5.7	6.3
Sep	8.5	7.9	6.9	4.4	4.0	4.0	4.4	5.9	6.6

Monthly Average DO for No Discharge with a Net Flow of 500 cfs									
	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.2	7.5	6.7	6.6	6.7	6.9	7.6	7.9
Nov	8.9	8.7	8.4	7.4	7.3	7.3	7.4	7.9	8.1
Dec	9.3	9.2	9.0	8.4	8.3	8.3	8.3	8.6	8.7
Jan	9.6	9.5	9.4	8.9	8.9	8.9	8.9	9.1	9.2
Feb	9.4	9.4	9.2	8.8	8.7	8.7	8.8	9.1	9.1
Mar	9.5	9.2	8.9	8.4	8.4	8.4	8.5	8.8	8.9
Apr	8.5	8.5	8.1	7.5	7.5	7.5	7.7	8.2	8.4
May	8.2	8.0	7.5	6.6	6.6	6.6	6.8	7.5	7.8
Jun	8.2	7.6	6.8	6.0	6.0	6.0	6.3	6.9	7.2
Jul	7.7	6.6	5.6	5.0	5.0	5.1	5.5	6.2	6.6
Aug	7.8	7.0	6.0	4.9	4.8	4.9	5.2	6.0	6.5
Sep	8.5	7.9	7.1	5.9	5.8	5.8	6.0	6.7	7.0

Monthly Average DO Change for No Discharge with a Net Flow of 500 cfs									
Station 8	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	0.0	-0.0	0.1	0.6	0.7	0.7	0.6	0.3	0.2
Nov	0.0	-0.0	0.1	1.0	1.3	1.3	1.3	0.8	0.5
Dec	0.0	-0.0	-0.0	0.8	1.0	1.1	1.1	0.7	0.4
Jan	0.0	-0.0	-0.0	0.9	1.1	1.2	1.2	0.7	0.4
Feb	0.0	-0.0	-0.0	1.3	1.6	1.7	1.6	1.0	0.6
Mar	0.0	-0.1	-0.1	1.1	1.3	1.4	1.4	0.8	0.5
Apr	0.0	-0.0	0.0	0.5	0.7	0.7	0.7	0.4	0.2
May	0.0	0.0	-0.0	0.1	0.2	0.2	0.2	0.1	0.1
Jun	0.0	0.0	-0.0	0.1	0.1	0.2	0.2	0.1	0.0
Jul	0.0	-0.0	0.0	0.2	0.2	0.2	0.2	0.1	0.0
Aug	0.0	0.0	0.1	0.7	0.8	0.8	0.7	0.3	0.2
Sep	0.0	0.0	0.2	1.5	1.8	1.8	1.6	0.8	0.5

Table 9. Stockton DO Model Results for Net Stockton Flow of 1,000 cfs:
1996 Discharge versus No Discharge

Monthly Average DO for 1996 Discharge with a Net Flow of 1,000 cfs									
	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.3	8.0	6.9	6.6	6.5	6.5	7.0	7.4
Nov	8.9	8.8	8.6	7.7	7.4	7.2	7.1	7.3	7.6
Dec	9.3	9.3	9.2	8.6	8.4	8.3	8.2	8.2	8.4
Jan	9.6	9.6	9.5	8.9	8.7	8.7	8.6	8.7	8.9
Feb	9.4	9.4	9.3	8.6	8.4	8.3	8.3	8.5	8.7
Mar	9.5	9.4	9.2	8.4	8.2	8.2	8.1	8.4	8.6
Apr	8.5	8.5	8.4	7.8	7.6	7.5	7.5	7.8	8.1
May	8.2	8.1	7.9	7.3	7.1	7.0	7.0	7.4	7.7
Jun	8.2	7.8	7.4	6.7	6.6	6.5	6.5	6.8	7.1
Jul	7.7	7.0	6.3	5.4	5.3	5.2	5.3	5.9	6.3
Aug	7.8	7.3	6.7	5.3	5.0	4.9	4.8	5.5	6.0
Sep	8.5	8.2	7.7	6.3	5.8	5.7	5.5	5.9	6.5

Monthly Average DO for No Discharge with a Net Flow of 1,000 cfs									
	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.3	8.0	7.2	6.9	6.9	6.9	7.3	7.7
Nov	8.9	8.8	8.6	8.0	7.9	7.8	7.7	7.9	8.1
Dec	9.3	9.3	9.2	8.8	8.7	8.7	8.7	8.7	8.8
Jan	9.6	9.6	9.5	9.2	9.1	9.0	9.0	9.1	9.2
Feb	9.4	9.4	9.3	9.0	9.0	8.9	8.9	9.1	9.1
Mar	9.5	9.4	9.1	8.7	8.6	8.6	8.6	8.8	8.9
Apr	8.5	8.5	8.4	7.9	7.8	7.8	7.8	8.1	8.3
May	8.2	8.1	7.9	7.3	7.1	7.1	7.1	7.4	7.7
Jun	8.2	7.8	7.4	6.8	6.6	6.6	6.6	6.9	7.2
Jul	7.7	7.0	6.3	5.5	5.4	5.3	5.5	6.0	6.4
Aug	7.8	7.3	6.7	5.7	5.4	5.4	5.3	5.8	6.2
Sep	8.5	8.2	7.7	6.9	6.7	6.6	6.5	6.7	7.0

Monthly Average DO Change for No Discharge with a Net Flow of 1,000 cfs									
	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	0.0	0.0	0.0	0.2	0.3	0.4	0.4	0.3	0.2
Nov	0.0	-0.0	-0.0	0.4	0.5	0.5	0.6	0.6	0.4
Dec	0.0	-0.0	-0.0	0.2	0.3	0.4	0.5	0.5	0.4
Jan	0.0	-0.0	0.0	0.2	0.3	0.4	0.4	0.4	0.3
Feb	0.0	-0.0	-0.0	0.4	0.5	0.6	0.7	0.6	0.4
Mar	0.0	-0.0	-0.1	0.3	0.3	0.4	0.5	0.4	0.3
Apr	0.0	-0.0	-0.0	0.1	0.2	0.2	0.3	0.3	0.2
May	0.0	0.0	-0.0	0.0	0.1	0.1	0.1	0.1	0.1
Jun	0.0	0.0	-0.0	0.0	0.0	0.1	0.1	0.1	0.1
Jul	0.0	-0.0	-0.0	0.0	0.1	0.1	0.1	0.1	0.1
Aug	0.0	0.0	0.0	0.3	0.4	0.5	0.5	0.4	0.2
Sep	0.0	0.0	0.0	0.7	0.8	0.9	1.0	0.8	0.5

Table 10. Stockton DO Model Results for 1996 Discharge:
Net Stockton Flow of 0 cfs versus Net Flow of 1,000 cfs

Monthly Average DO for 1996 Discharge with Net Flow of 0 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	6.4	5.8	5.7	6.0	6.3	6.9	7.8	8.0
Nov	8.9	6.7	5.3	4.3	4.6	5.1	6.1	7.7	8.1
Dec	9.3	7.7	6.4	5.2	5.4	5.8	6.6	8.1	8.5
Jan	9.6	8.3	6.9	5.7	5.9	6.3	7.1	8.5	8.8
Feb	9.4	7.2	5.5	4.3	4.7	5.2	6.4	8.3	8.7
Mar	9.5	7.1	5.6	4.3	4.8	5.2	6.4	8.2	8.6
Apr	8.5	6.9	5.9	5.2	5.5	5.9	6.9	8.1	8.3
May	8.2	6.4	5.9	5.5	5.8	6.1	6.8	7.7	8.0
Jun	8.2	5.6	5.3	5.0	5.3	5.6	6.3	7.1	7.4
Jul	7.7	5.0	4.6	4.4	4.7	5.0	5.7	6.6	6.8
Aug	7.8	4.6	3.7	3.3	3.7	4.2	5.1	6.3	6.7
Sep	8.5	4.8	3.1	2.3	2.8	3.4	4.7	6.5	7.0

Monthly Average DO for 1996 Discharge with Net Flow of 1,000 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.3	8.0	6.9	6.6	6.5	6.5	7.0	7.4
Nov	8.9	8.8	8.6	7.7	7.4	7.2	7.1	7.3	7.6
Dec	9.3	9.3	9.2	8.6	8.4	8.3	8.2	8.2	8.4
Jan	9.6	9.6	9.5	8.9	8.7	8.7	8.6	8.7	8.9
Feb	9.4	9.4	9.3	8.6	8.4	8.3	8.3	8.5	8.7
Mar	9.5	9.4	9.2	8.4	8.2	8.2	8.1	8.4	8.6
Apr	8.5	8.5	8.4	7.8	7.6	7.5	7.5	7.8	8.1
May	8.2	8.1	7.9	7.3	7.1	7.0	7.0	7.4	7.7
Jun	8.2	7.8	7.4	6.7	6.6	6.5	6.5	6.8	7.1
Jul	7.7	7.0	6.3	5.4	5.3	5.2	5.3	5.9	6.3
Aug	7.8	7.3	6.7	5.3	5.0	4.9	4.8	5.5	6.0
Sep	8.5	8.2	7.7	6.3	5.8	5.7	5.5	5.9	6.5

Monthly Average DO Change for a Net Flow Increase of 1,000 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	0.0	1.9	2.2	1.2	0.6	0.3	-0.4	-0.8	-0.6
Nov	0.0	2.1	3.4	3.4	2.8	2.2	1.0	-0.4	-0.4
Dec	0.0	1.6	2.8	3.5	3.0	2.5	1.5	0.1	-0.1
Jan	0.0	1.3	2.6	3.2	2.8	2.4	1.5	0.2	0.1
Feb	0.0	2.2	3.8	4.3	3.7	3.1	1.9	0.2	0.0
Mar	0.0	2.3	3.6	4.1	3.5	2.9	1.7	0.2	0.0
Apr	0.0	1.6	2.4	2.6	2.1	1.6	0.6	-0.2	-0.2
May	0.0	1.7	2.0	1.8	1.3	0.9	0.1	-0.4	-0.3
Jun	0.0	2.2	2.1	1.7	1.3	0.9	0.2	-0.3	-0.2
Jul	0.0	2.0	1.7	1.0	0.5	0.2	-0.4	-0.6	-0.4
Aug	0.0	2.6	3.0	2.0	1.3	0.7	-0.3	-0.8	-0.7
Sep	0.0	3.4	4.6	3.9	3.0	2.2	0.7	-0.6	-0.5

Table 11. Stockton DO Model Results for Net Stockton Flow of 1,000 cfs:
1996 Discharge versus 1996 Discharge with 4,500-lb/day Aeration

Monthly Average DO for 1996 Discharge with a Net Flow of 1,000 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.3	8.0	6.9	6.6	6.5	6.5	7.0	7.4
Nov	8.9	8.8	8.6	7.7	7.4	7.2	7.1	7.3	7.6
Dec	9.3	9.3	9.2	8.6	8.4	8.3	8.2	8.2	8.4
Jan	9.6	9.6	9.5	8.9	8.7	8.7	8.6	8.7	8.9
Feb	9.4	9.4	9.3	8.6	8.4	8.3	8.3	8.5	8.7
Mar	9.5	9.4	9.2	8.4	8.2	8.2	8.1	8.4	8.6
Apr	8.5	8.5	8.4	7.8	7.6	7.5	7.5	7.8	8.1
May	8.2	8.1	7.9	7.3	7.1	7.0	7.0	7.4	7.7
Jun	8.2	7.8	7.4	6.7	6.6	6.5	6.5	6.8	7.1
Jul	7.7	7.0	6.3	5.4	5.3	5.2	5.3	5.9	6.3
Aug	7.8	7.3	6.7	5.3	5.0	4.9	4.8	5.5	6.0
Sep	8.5	8.2	7.7	6.3	5.8	5.7	5.5	5.9	6.5

Monthly Average DO for 4,500-lb/day Aeration with a Net Flow of 1,000 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.3	8.0	6.9	6.6	6.5	6.5	7.0	7.4
Nov	8.9	8.8	8.6	7.7	7.4	7.2	7.1	7.3	7.6
Dec	9.3	9.3	9.2	8.6	8.4	8.3	8.2	8.2	8.4
Jan	9.6	9.6	9.5	8.9	8.7	8.7	8.6	8.7	8.9
Feb	9.4	9.4	9.3	8.6	8.4	8.3	8.3	8.5	8.7
Mar	9.5	9.4	9.2	8.4	8.2	8.2	8.1	8.4	8.6
Apr	8.5	8.5	8.4	7.8	7.6	7.5	7.5	7.8	8.1
May	8.2	8.1	7.9	7.3	7.1	7.0	7.0	7.4	7.7
Jun	8.2	7.8	7.7	7.3	7.1	7.0	6.8	7.0	7.2
Jul	7.7	7.0	6.5	6.0	5.8	5.7	5.7	6.2	6.5
Aug	7.8	7.3	6.9	6.0	5.6	5.4	5.2	5.7	6.2
Sep	8.5	8.2	7.8	6.9	6.4	6.2	5.9	6.2	6.6

Monthly Average DO Change for 4,500-lb/day Aeration with a Net Flow of 1,000 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nov	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	0.0	0.0	0.2	0.6	0.5	0.4	0.3	0.2	0.1
Jul	0.0	0.0	0.2	0.6	0.6	0.5	0.4	0.2	0.1
Aug	0.0	0.0	0.2	0.6	0.5	0.5	0.4	0.2	0.1
Sep	0.0	0.0	0.1	0.6	0.6	0.5	0.4	0.2	0.1

Table 12. Stockton DO Model Results for Net Stockton Flow of 1,000 cfs:
1996 Discharge versus 50% SOD Reduction

Monthly Average DO for 1996 Discharge with a Net Flow of 1,000 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.3	8.0	6.9	6.6	6.5	6.5	7.0	7.4
Nov	8.9	8.8	8.6	7.7	7.4	7.2	7.1	7.3	7.6
Dec	9.3	9.3	9.2	8.6	8.4	8.3	8.2	8.2	8.4
Jan	9.6	9.6	9.5	8.9	8.7	8.7	8.6	8.7	8.9
Feb	9.4	9.4	9.3	8.6	8.4	8.3	8.3	8.5	8.7
Mar	9.5	9.4	9.2	8.4	8.2	8.2	8.1	8.4	8.6
Apr	8.5	8.5	8.4	7.8	7.6	7.5	7.5	7.8	8.1
May	8.2	8.1	7.9	7.3	7.1	7.0	7.0	7.4	7.7
Jun	8.2	7.8	7.4	6.7	6.6	6.5	6.5	6.8	7.1
Jul	7.7	7.0	6.3	5.4	5.3	5.2	5.3	5.9	6.3
Aug	7.8	7.3	6.7	5.3	5.0	4.9	4.8	5.5	6.0
Sep	8.5	8.2	7.7	6.3	5.8	5.7	5.5	5.9	6.5

Monthly Average DO for 1996 Discharge with a Net Flow of 1,000 cfs and 50% SOD

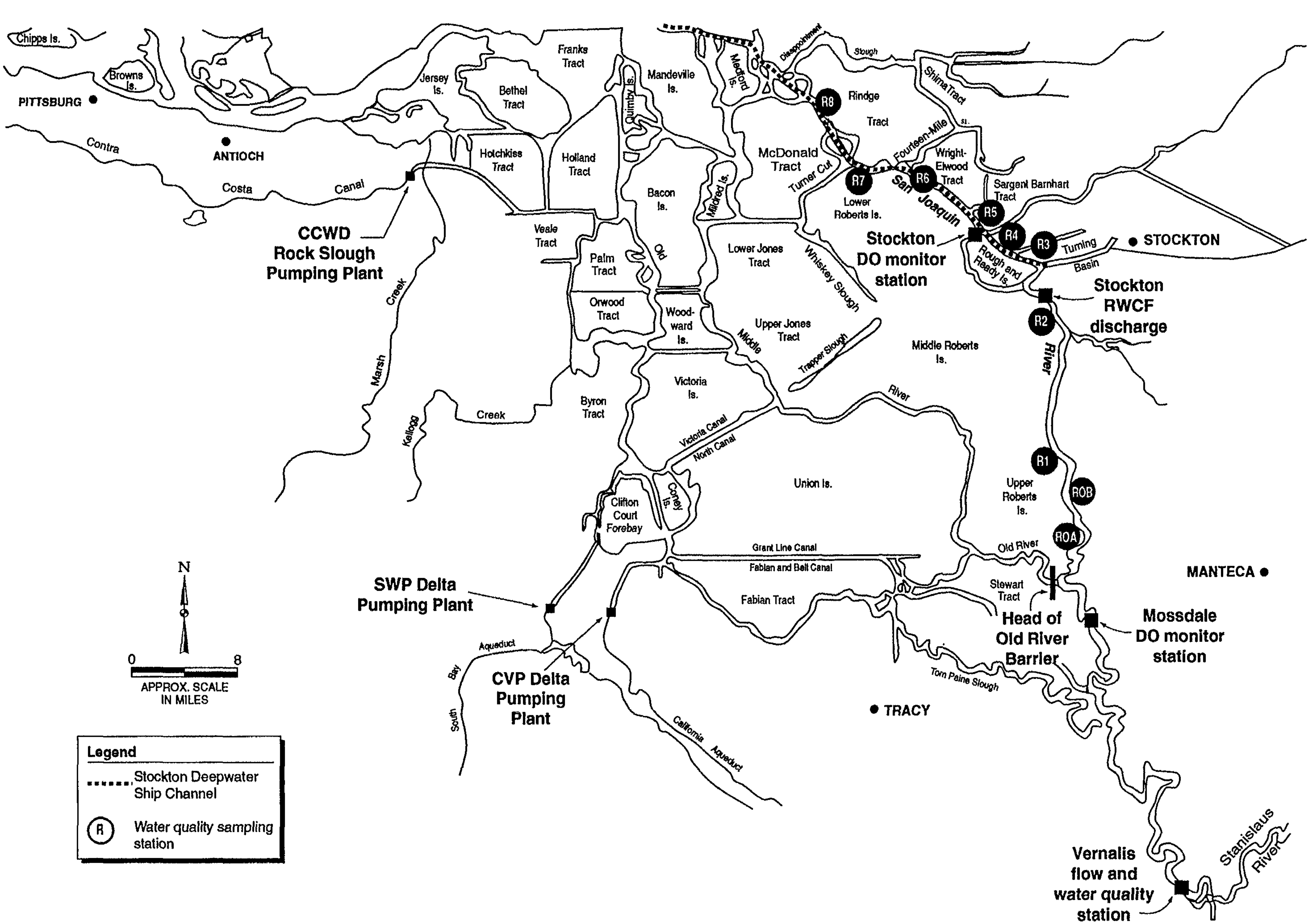
	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	8.6	8.5	8.3	7.5	7.2	7.1	7.1	7.5	7.8
Nov	8.9	8.9	8.9	8.2	8.0	7.9	7.8	7.9	8.1
Dec	9.3	9.4	9.4	9.1	8.9	8.9	8.8	8.8	8.8
Jan	9.6	9.7	9.8	9.4	9.2	9.2	9.1	9.2	9.3
Feb	9.4	9.5	9.6	9.1	8.9	8.9	8.8	9.0	9.1
Mar	9.5	9.5	9.4	8.9	8.8	8.7	8.7	8.9	8.9
Apr	8.5	8.6	8.6	8.3	8.2	8.2	8.2	8.4	8.5
May	8.2	8.2	8.2	7.9	7.8	7.8	7.8	8.0	8.1
Jun	8.2	8.0	7.8	7.5	7.4	7.4	7.4	7.5	7.5
Jul	7.7	7.2	6.8	6.2	6.1	6.1	6.3	6.7	6.8
Aug	7.8	7.5	7.2	6.1	5.9	5.8	5.8	6.2	6.5
Sep	8.5	8.3	8.1	7.0	6.6	6.5	6.3	6.6	7.0

Monthly Average DO Change for 50% SOD Reduction with a Net Flow of 1,000 cfs

	Station 0	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Oct	0.0	0.1	0.3	0.5	0.6	0.6	0.6	0.5	0.4
Nov	0.0	0.1	0.3	0.5	0.6	0.7	0.7	0.6	0.4
Dec	0.0	0.1	0.3	0.5	0.5	0.6	0.6	0.6	0.4
Jan	0.0	0.1	0.3	0.4	0.5	0.5	0.6	0.5	0.4
Feb	0.0	0.1	0.3	0.5	0.5	0.6	0.6	0.5	0.4
Mar	0.0	0.1	0.2	0.5	0.5	0.6	0.6	0.5	0.4
Apr	0.0	0.1	0.2	0.5	0.6	0.7	0.7	0.6	0.4
May	0.0	0.1	0.3	0.6	0.7	0.8	0.8	0.6	0.4
Jun	0.0	0.2	0.4	0.7	0.8	0.8	0.9	0.7	0.4
Jul	0.0	0.2	0.5	0.8	0.9	0.9	0.9	0.7	0.5
Aug	0.0	0.2	0.5	0.8	0.9	0.9	0.9	0.7	0.5
Sep	0.0	0.2	0.4	0.7	0.8	0.8	0.8	0.7	0.5

FIGURES

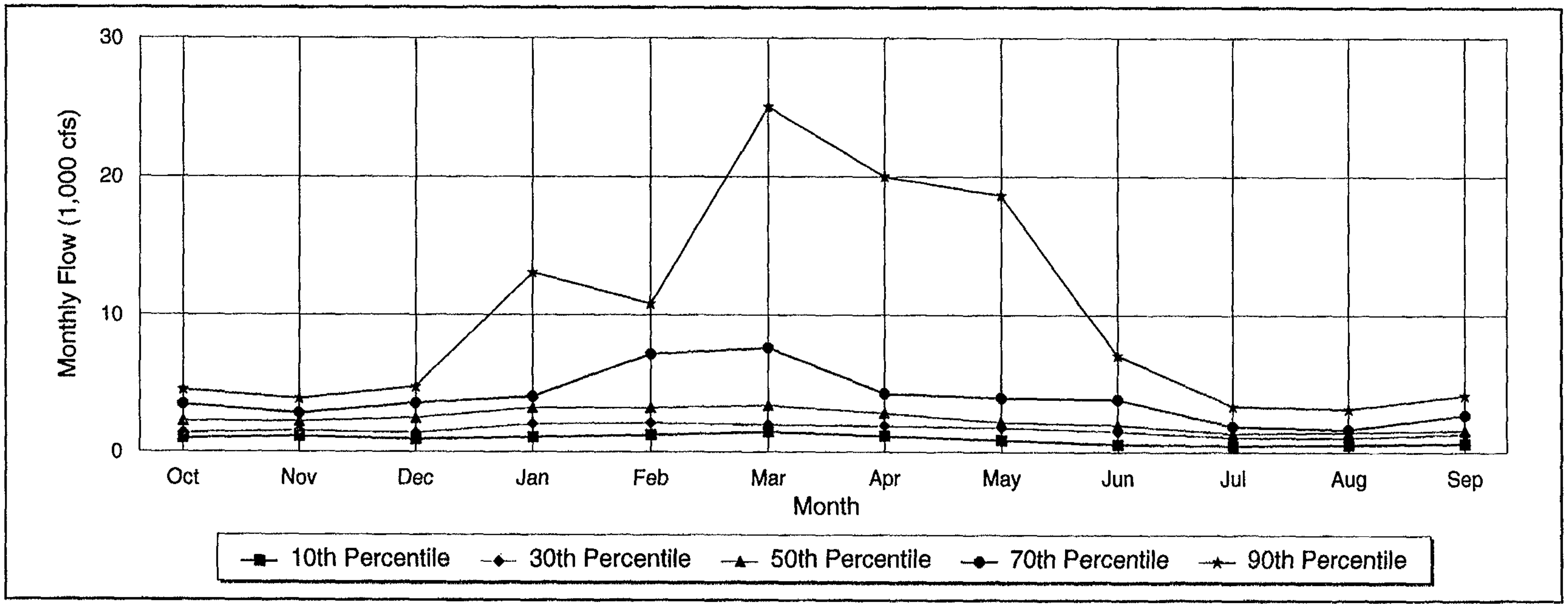
D-041958



Jones & Stokes Associates, Inc.

Figure 1
Location of Water Quality Stations on the San Joaquin River in the Vicinity of Stockton

D—041959



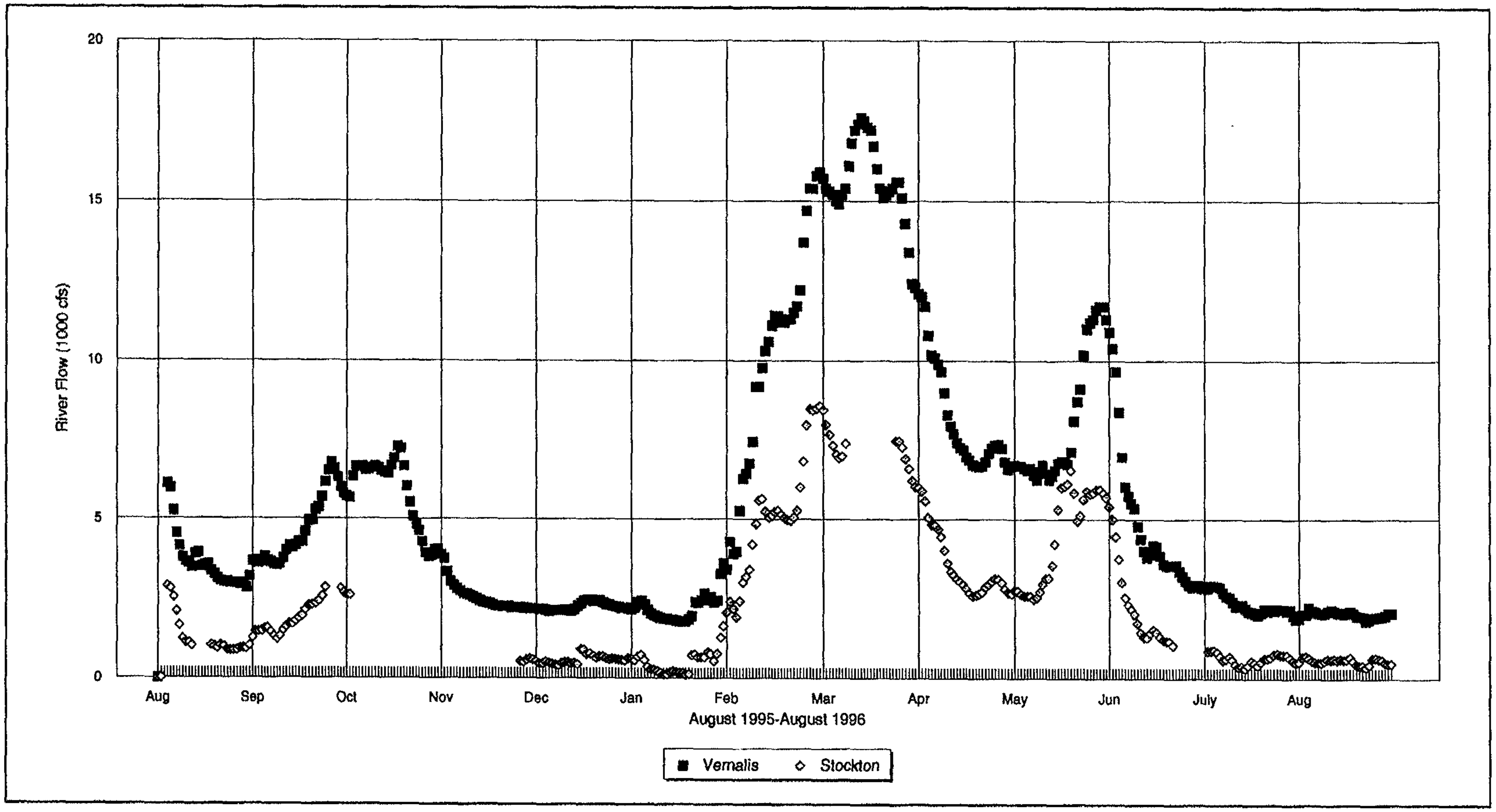
Historical Monthly Flows in the San Joaquin River at Vernalis (cfs) for the 1972-1992 Period of Record
Average Flow = 4,394 cfs ***Drainage Area = 13,536 sq. mi.*** **Data Source: USGS**

Percentile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TAF/yr
0%	246	430	506	816	758	524	212	400	118	93	124	179	416
10%	993	1,115	918	1,091	1,234	1,470	1,168	892	568	481	537	635	696
20%	1,274	1,274	1,278	1,255	1,389	1,779	1,309	1,049	798	671	1,033	1,067	1,059
30%	1,386	1,548	1,381	2,060	2,115	2,023	1,915	1,781	1,499	1,082	1,067	1,353	1,166
40%	1,992	1,646	2,205	2,305	2,701	2,736	2,466	1,967	1,711	1,284	1,269	1,471	1,765
50%	2,253	2,216	2,487	3,251	3,241	3,415	2,867	2,178	1,990	1,357	1,451	1,597	2,108
60%	2,790	2,311	2,812	3,766	6,212	5,685	3,957	2,937	2,297	1,636	1,615	1,925	2,614
70%	3,497	2,822	3,586	4,059	7,138	7,611	4,285	3,972	3,860	1,904	1,680	2,730	2,815
80%	3,814	3,498	3,745	5,233	7,988	10,062	10,249	8,764	5,708	2,557	2,179	2,917	5,227
90%	4,543	3,906	4,771	13,069	10,833	25,035	20,030	18,654	7,069	3,384	3,183	4,181	5,954
100%	13,316	10,675	19,126	25,632	31,604	40,035	36,447	31,771	26,083	19,227	9,035	11,310	15,406

Jones & Stokes Associates, Inc.

Figure 2
Distribution of Historical Monthly Flows in the San Joaquin River at Vernalis for Water Years 1972-1992

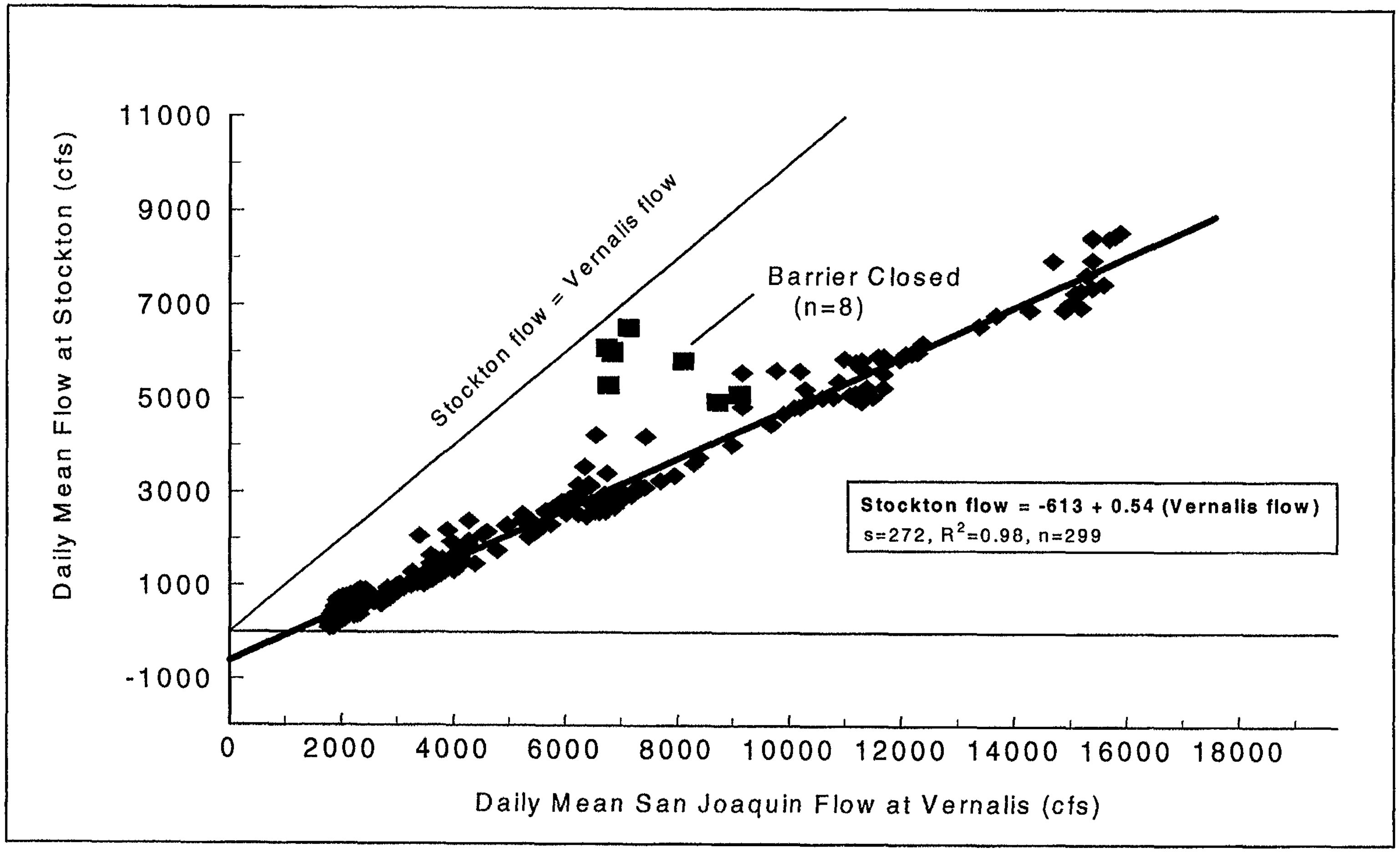
D-041960



Jones & Stokes Associates, Inc.

Figure 3
Daily Average Tidal Flow Measurements at Stockton Compared with San Joaquin River Flow at Vernalis for August 1995 to August 1996

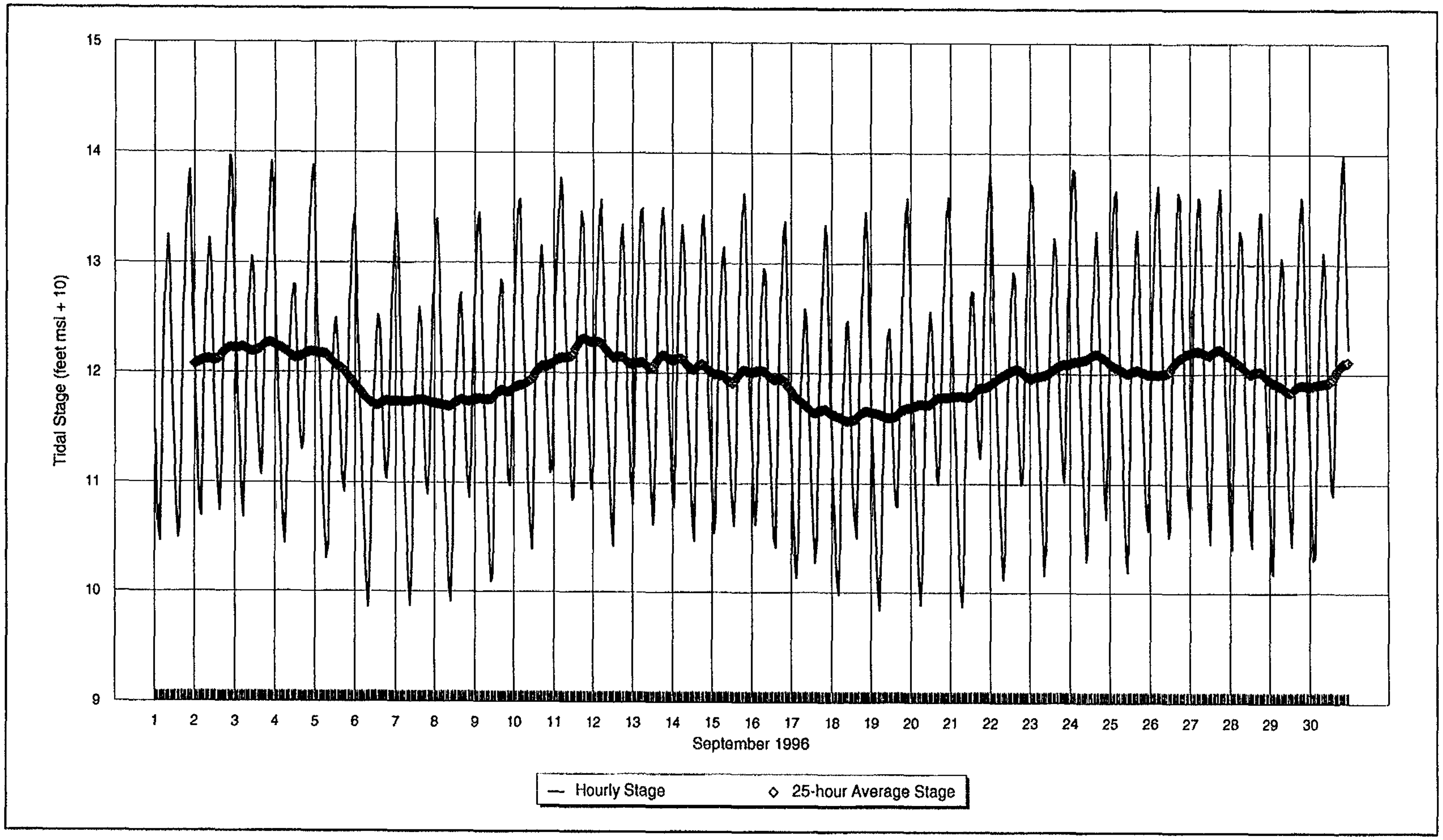
D-041962



Jones & Stokes Associates, Inc.

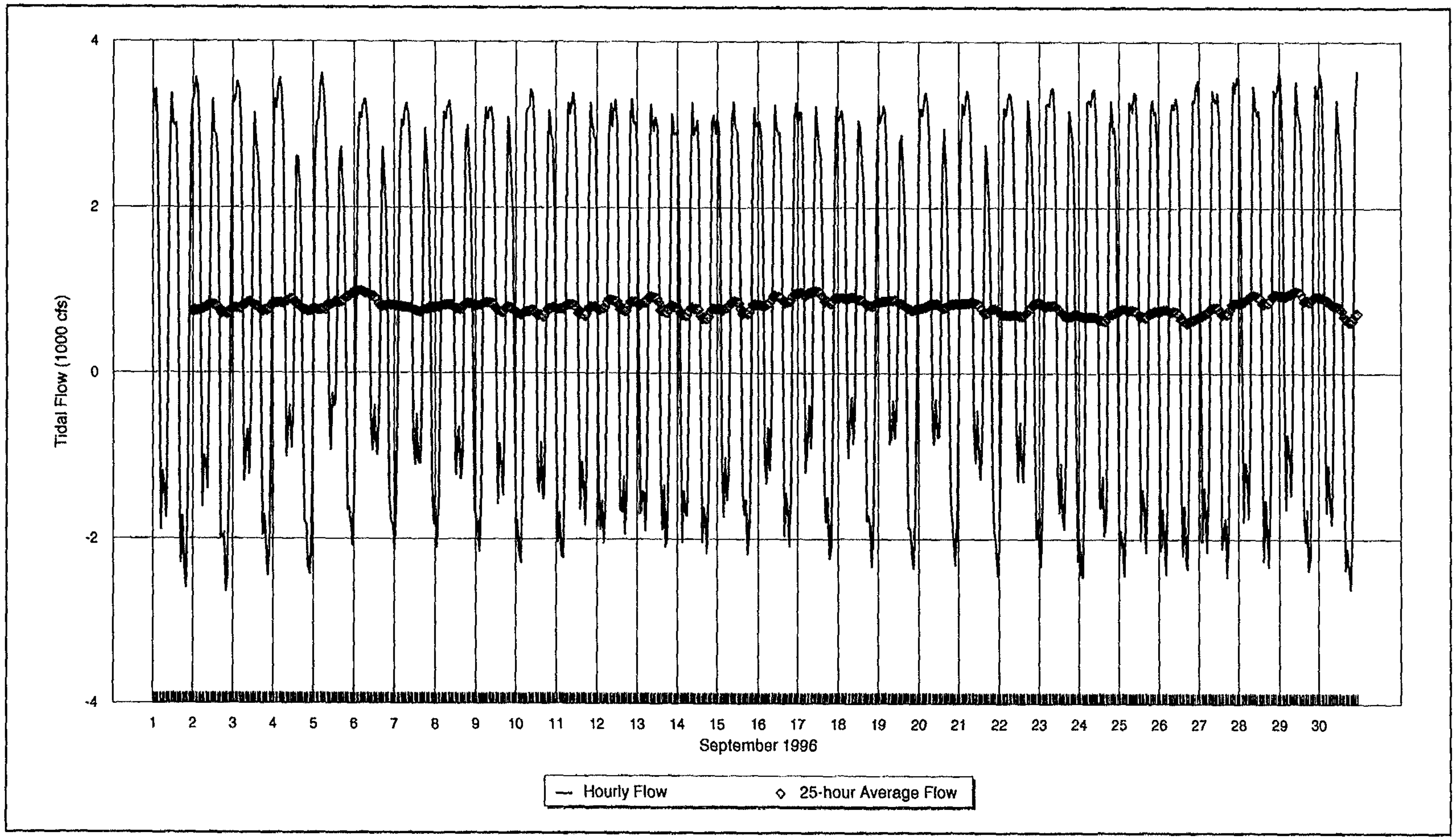
Figure 4
San Joaquin River, USGS UVM Station, 1995-1996

D—041962



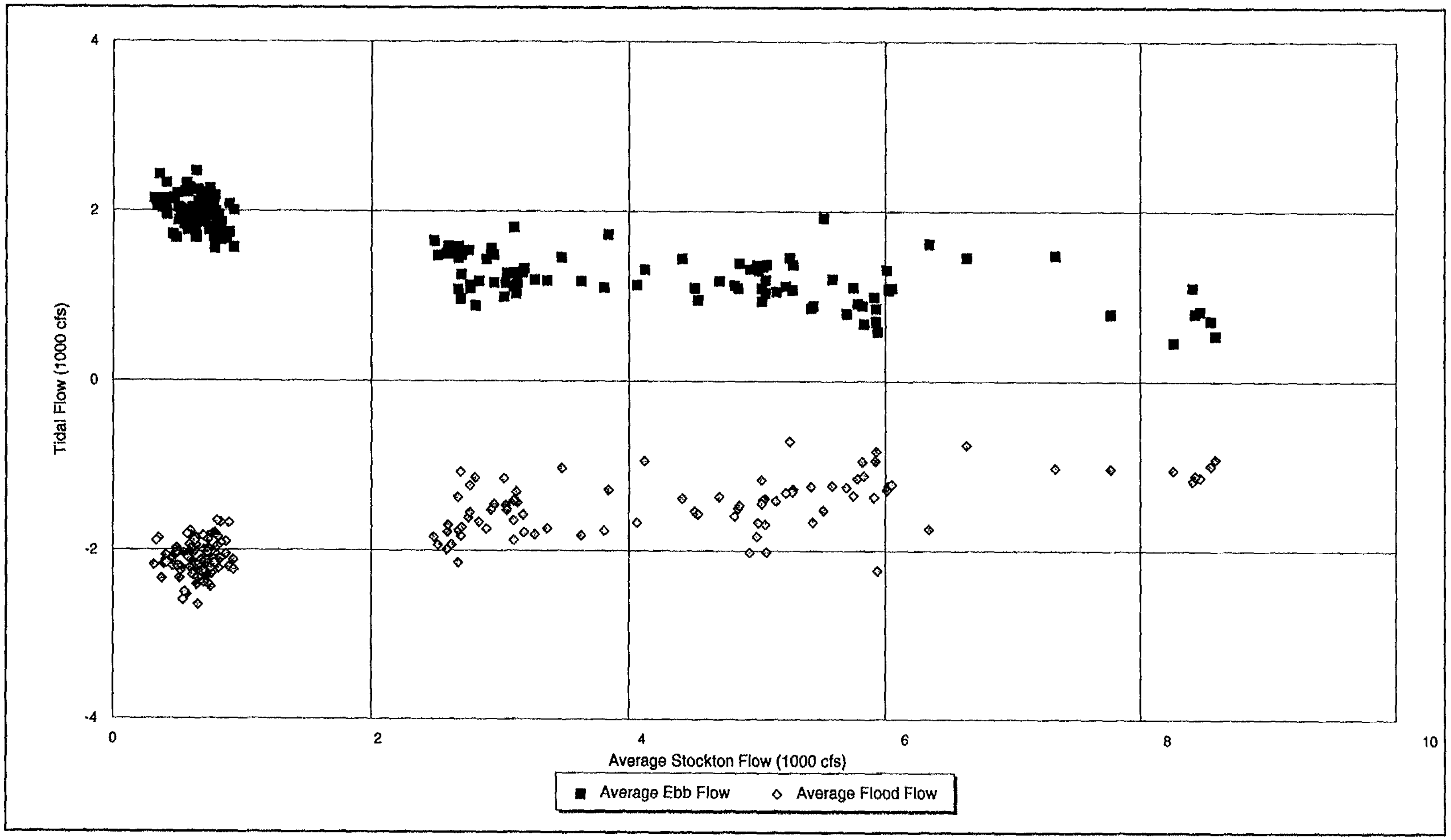
Jones & Stokes Associates, Inc.

Figure 5
Hourly Stage at Stockton
USGS UVM Station



Jones & Stokes Associates, Inc.

Figure 6
Hourly Flow at Stockton
USGS UVM Station



Jones & Stokes Associates, Inc.

Figure 7
Daily Average Tidal Flows at Stockton
USGS UVM Station

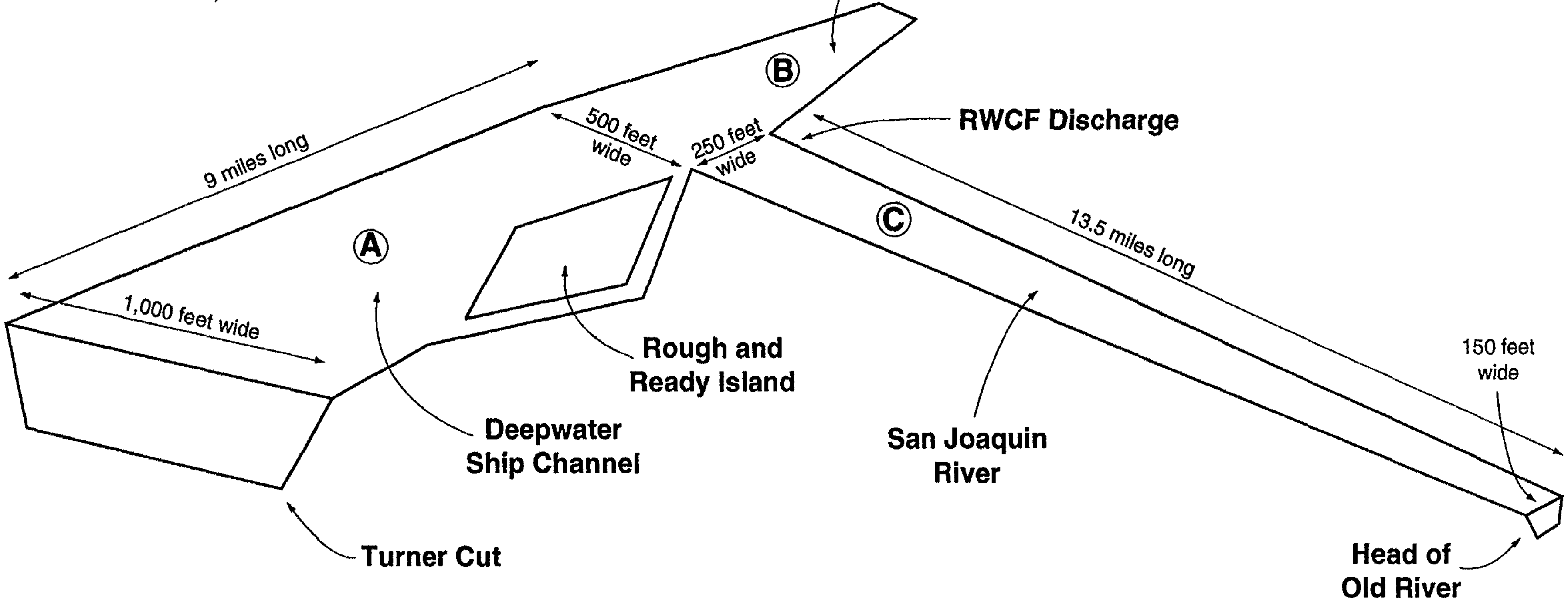
D-041966

Legend

A Deepwater Ship Channel
Area = 725 acres
Depth = 22 feet
Volume = 15,000 acre-feet

B Turning Basin
Area = 125 acres
Depth = 22 feet
Volume = 2,800 acre-feet

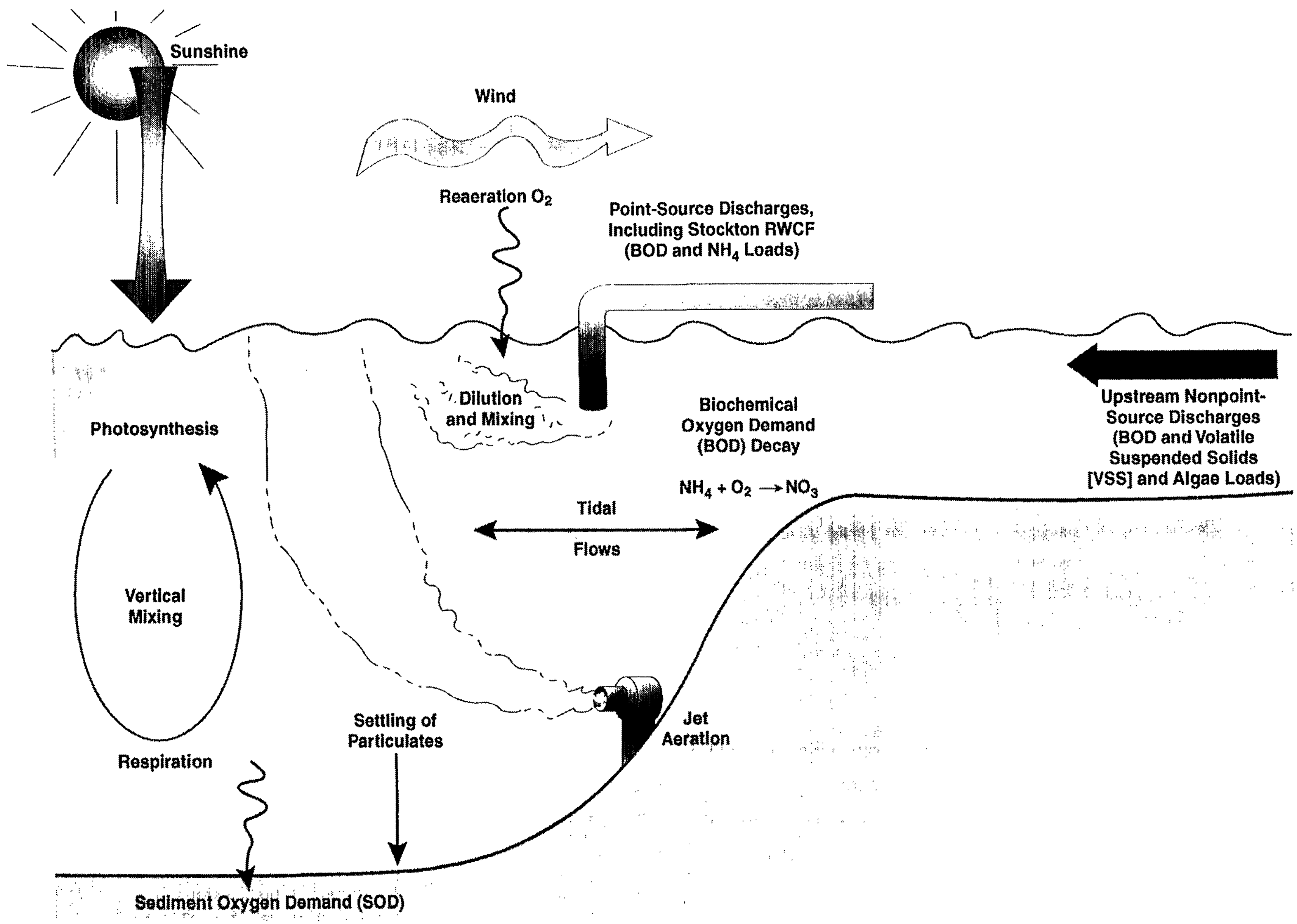
C San Joaquin River from Head of Old River to Turning Basin
Area = 300 acres
Depth = 8 feet
Volume = 2,500 acre-feet



D—041966

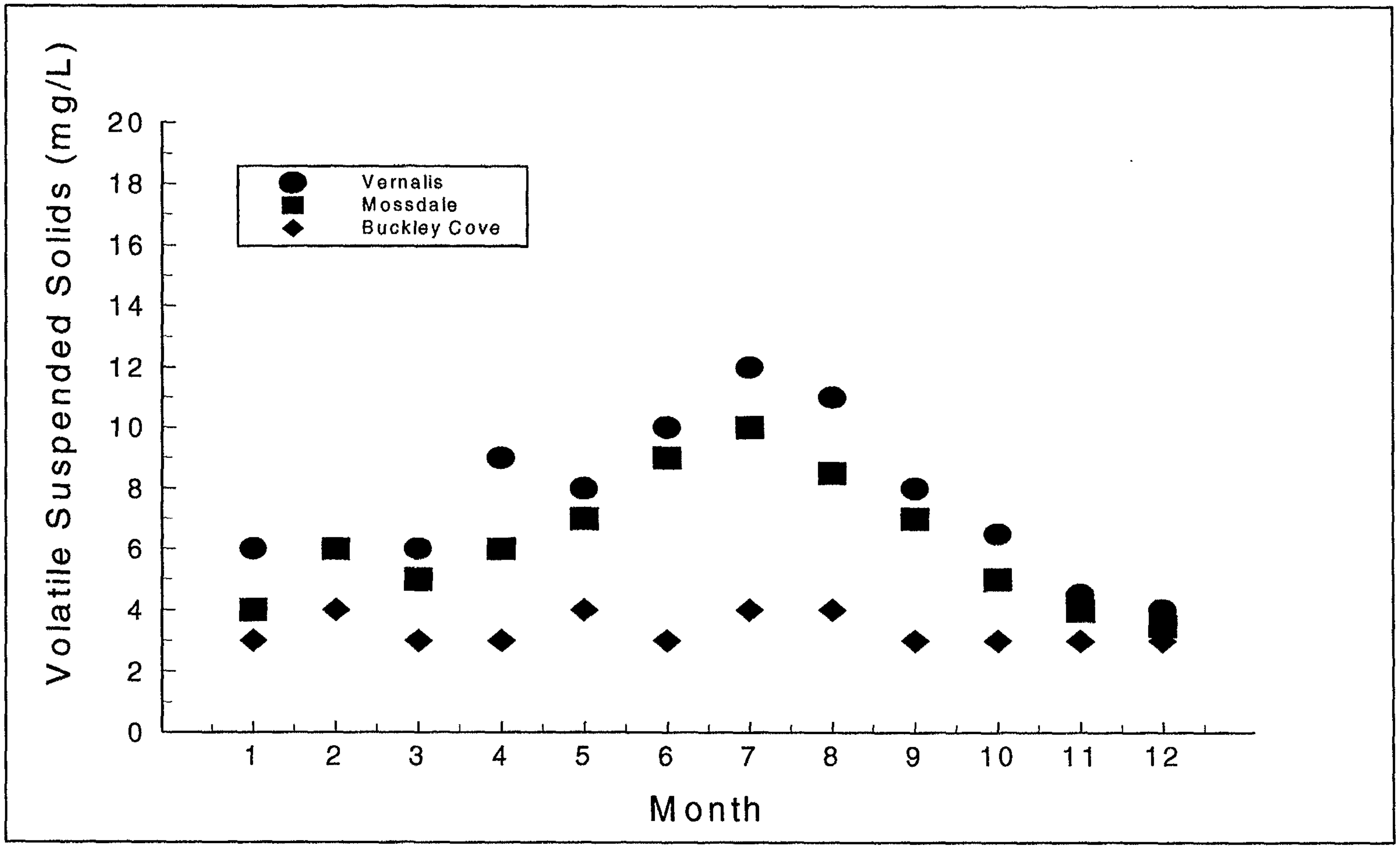
Jones & Stokes Associates, Inc.

Figure 8
San Joaquin River Channel Geometry between Head of Old River and Turner Cut



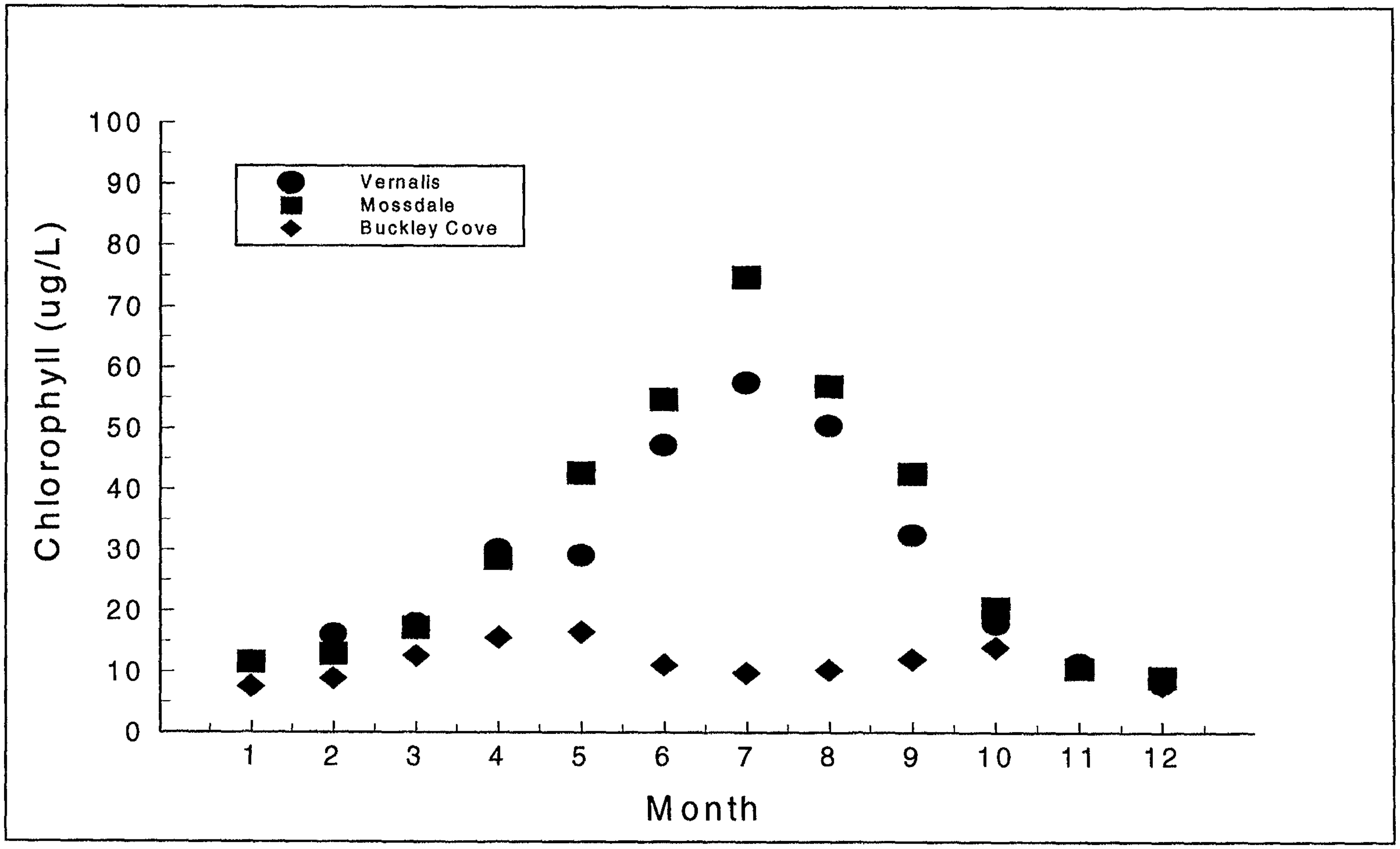
Jones & Stokes Associates, Inc.

Figure 9
Factors Affecting Dissolved Oxygen Concentration in the San Joaquin River



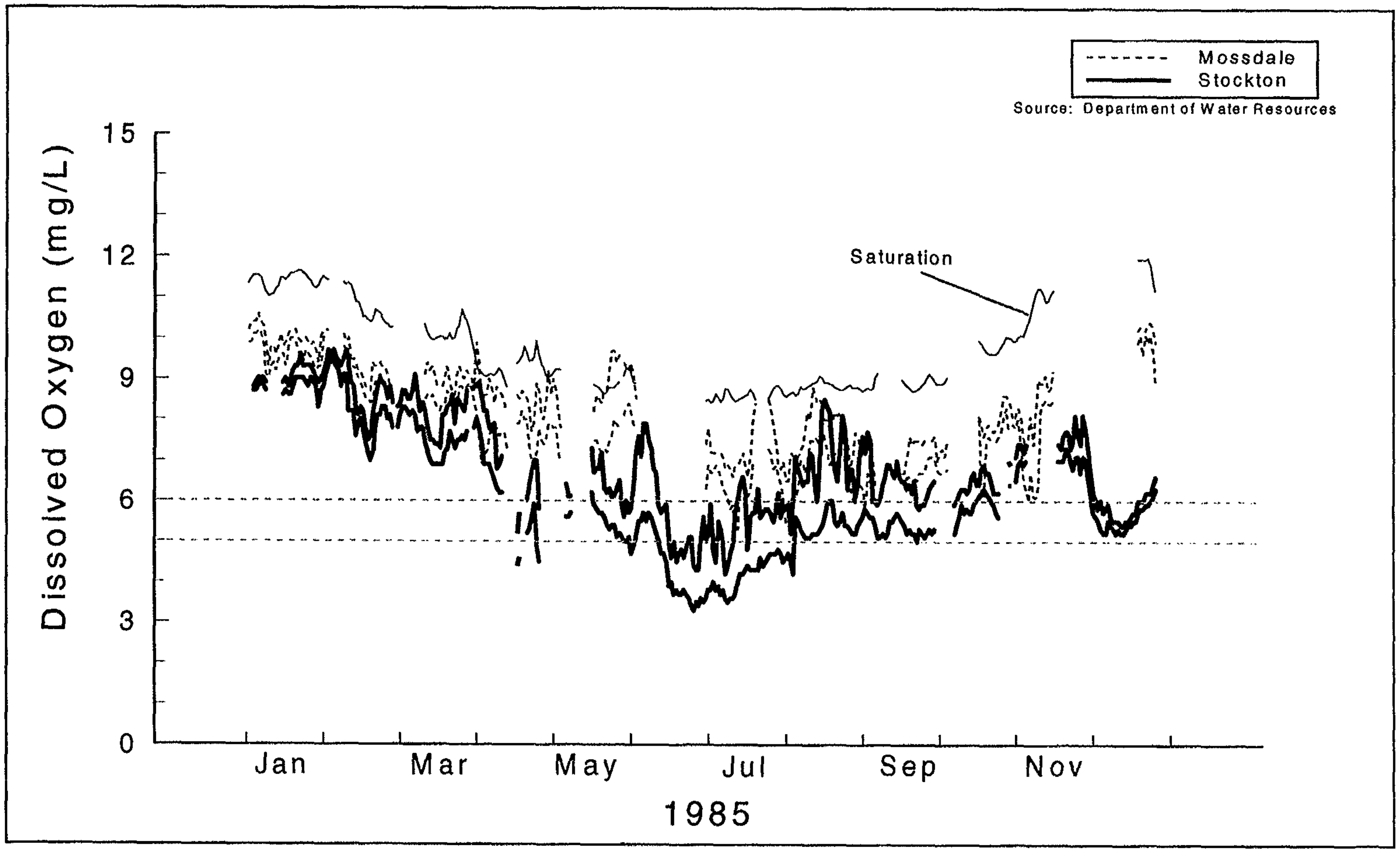
Jones & Stokes Associates, Inc.

Figure 10
Comparison of Monthly Median Volatile Suspended Solids at Three Locations in the San Joaquin River, 1975-1993



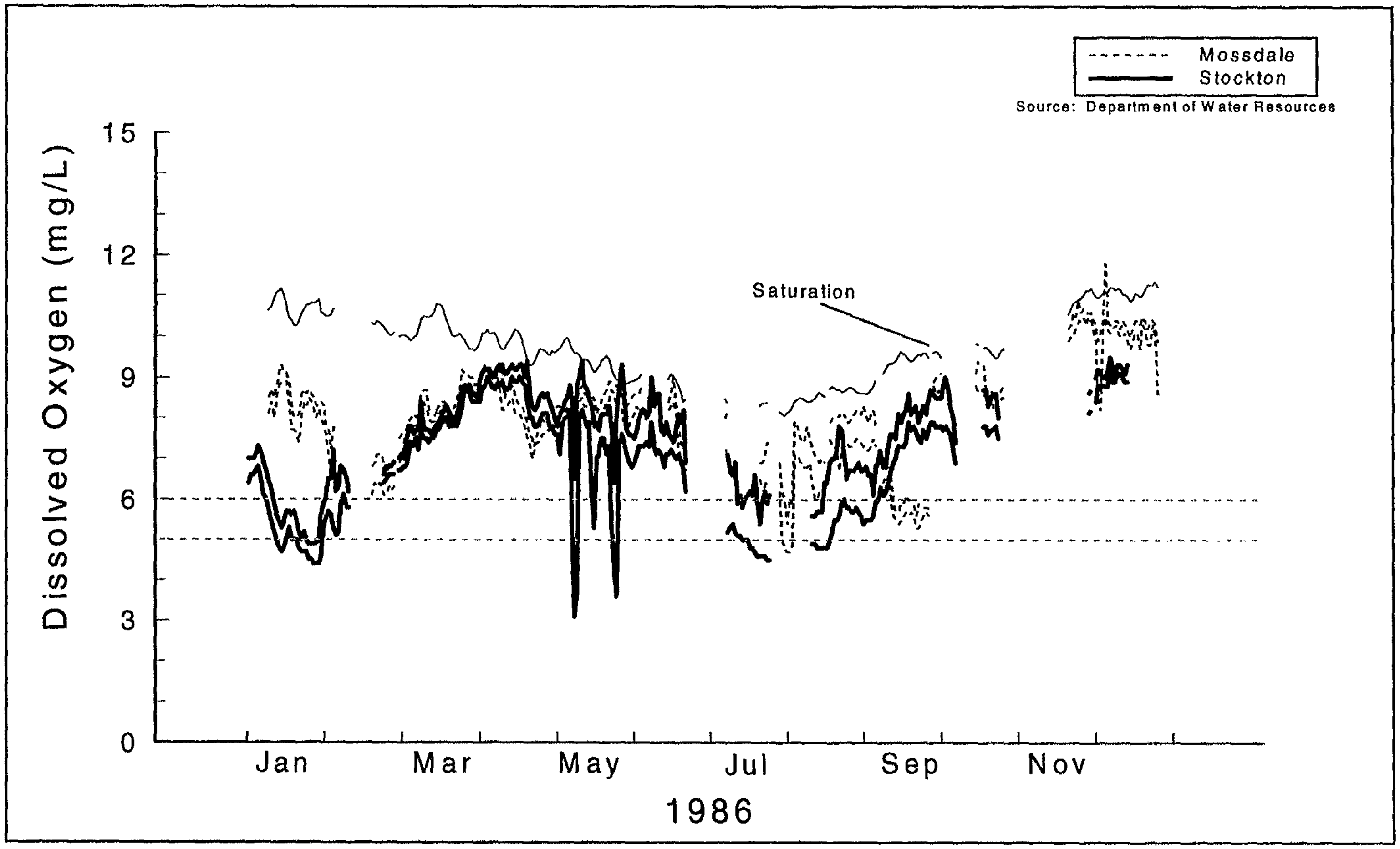
Jones & Stokes Associates, Inc.

Figure 11
Comparison of Monthly Median Chlorophyll Concentration at Three Locations in the San Joaquin River, 1975-1993



Jones & Stokes Associates, Inc.

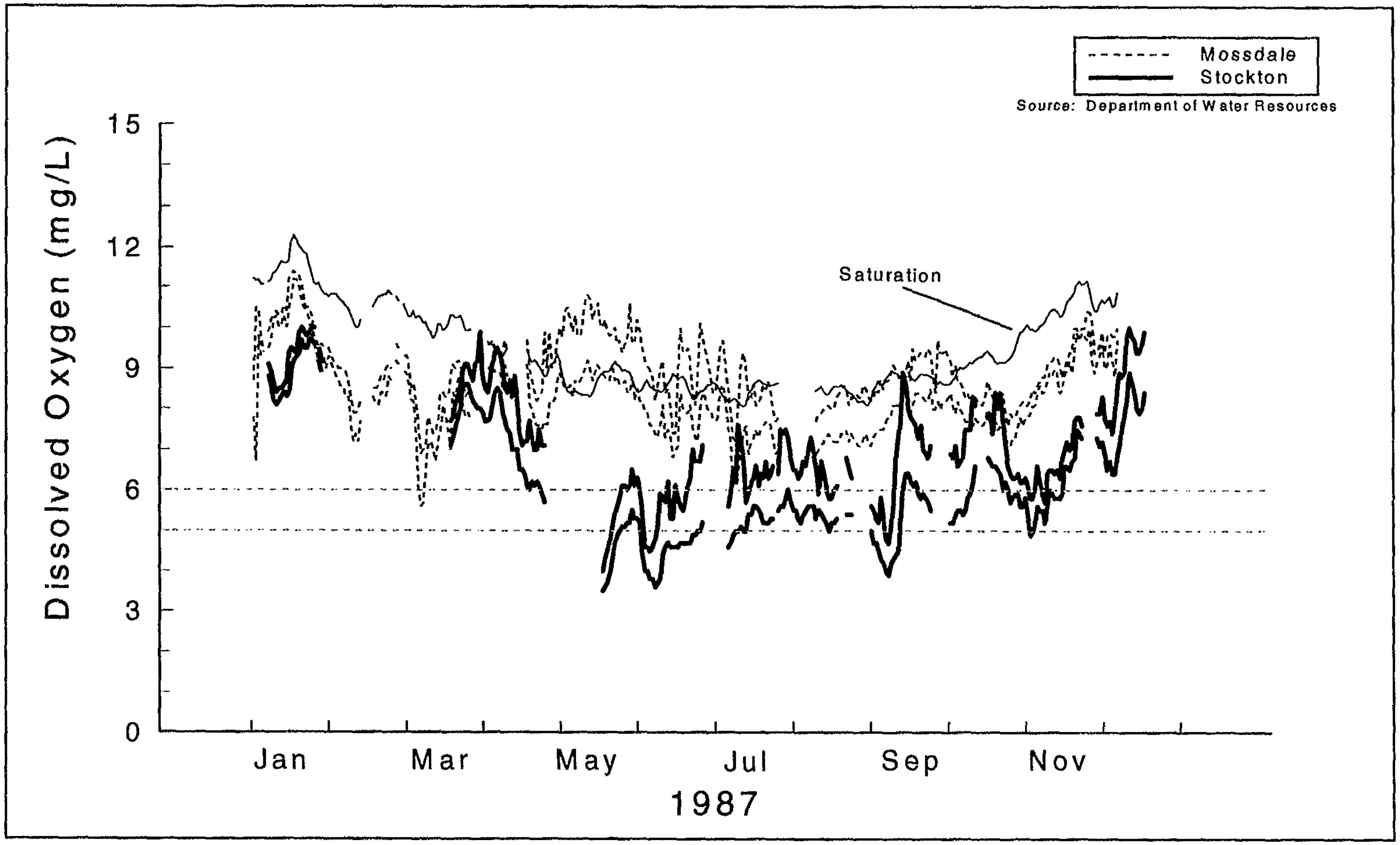
Figure 12a
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel



Jones & Stokes Associates, Inc.

Figure 12b
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel

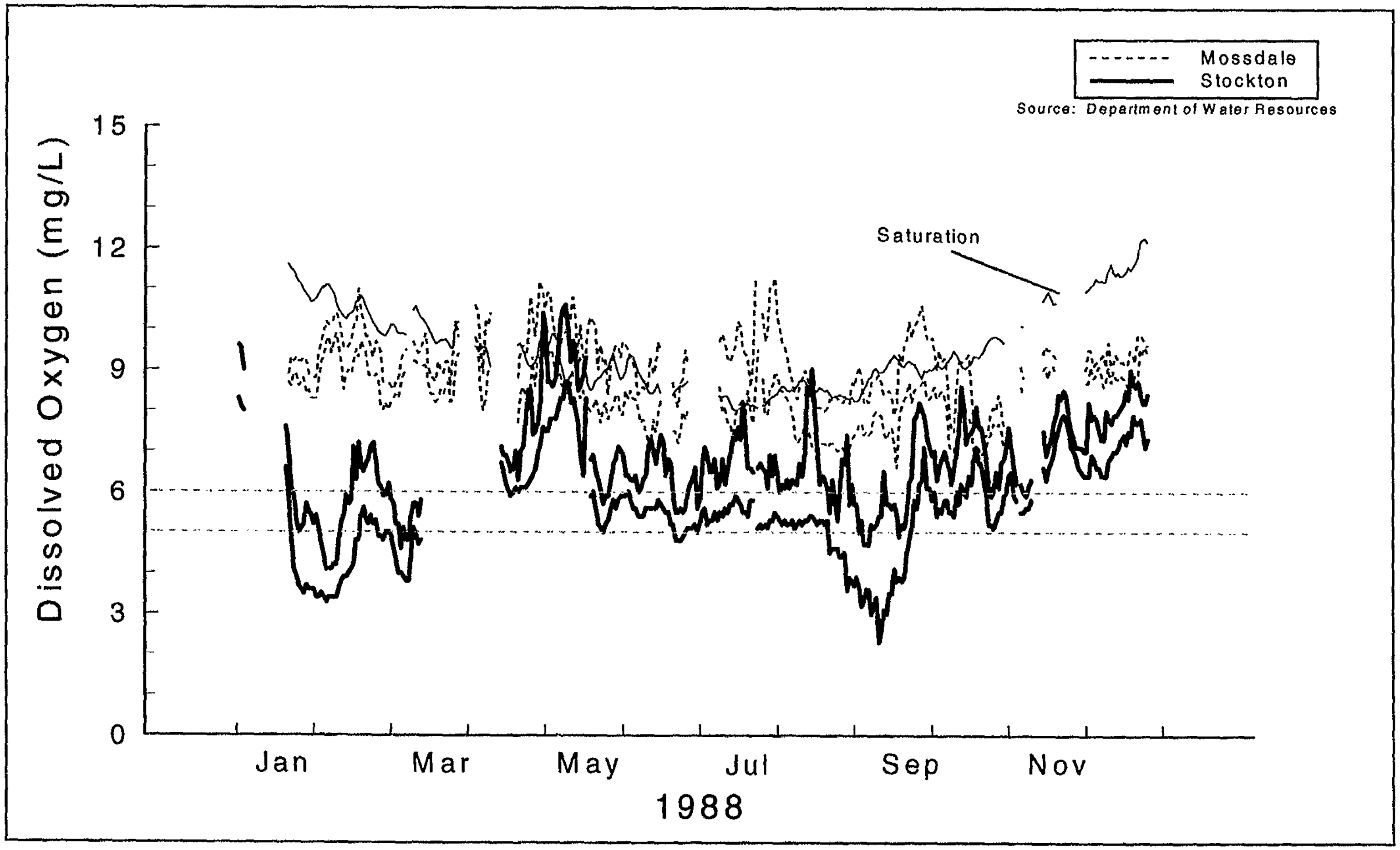
D-041971



Jones & Stokes Associates, Inc.

Figure 12c
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel

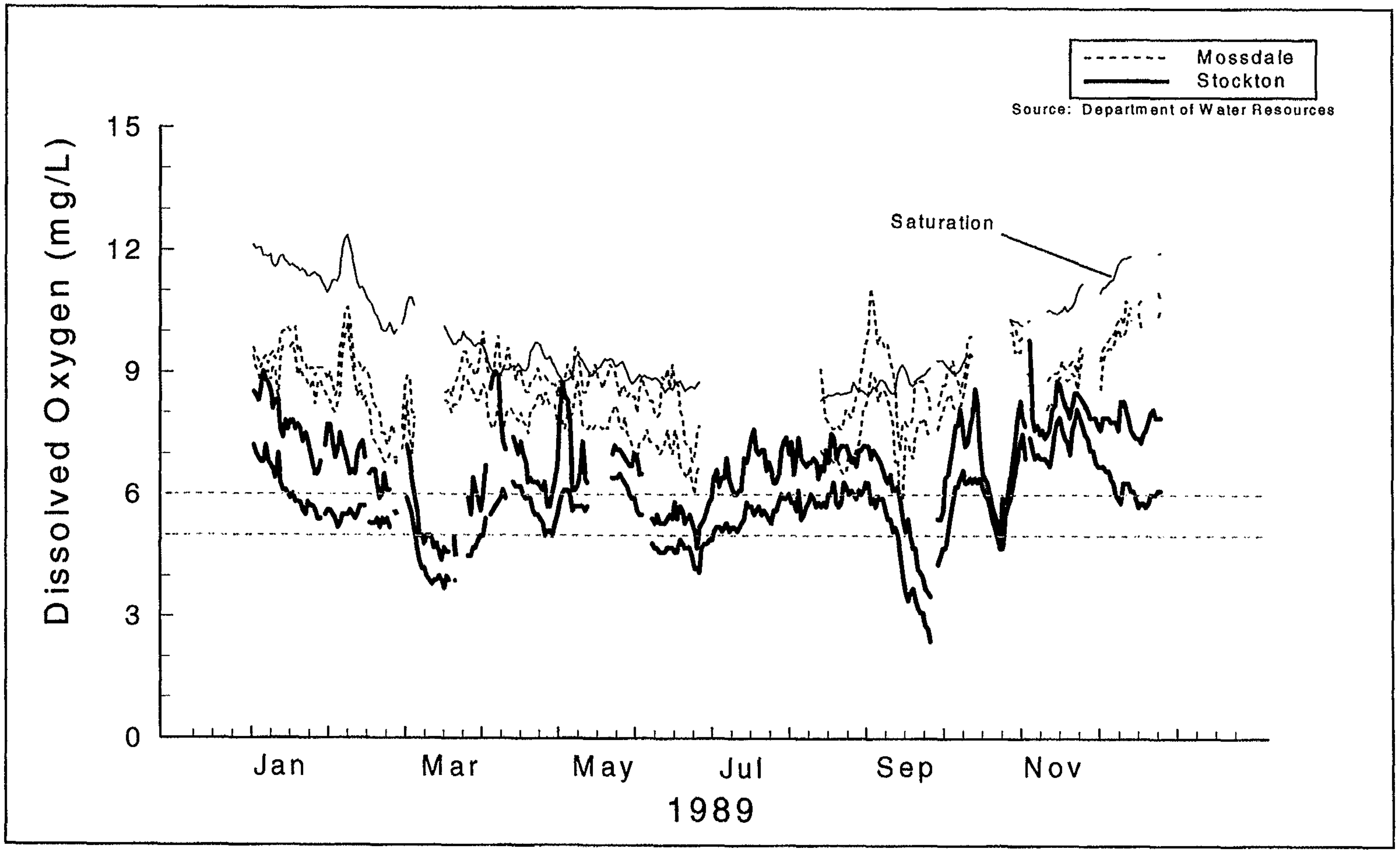
D-041973



D-041973

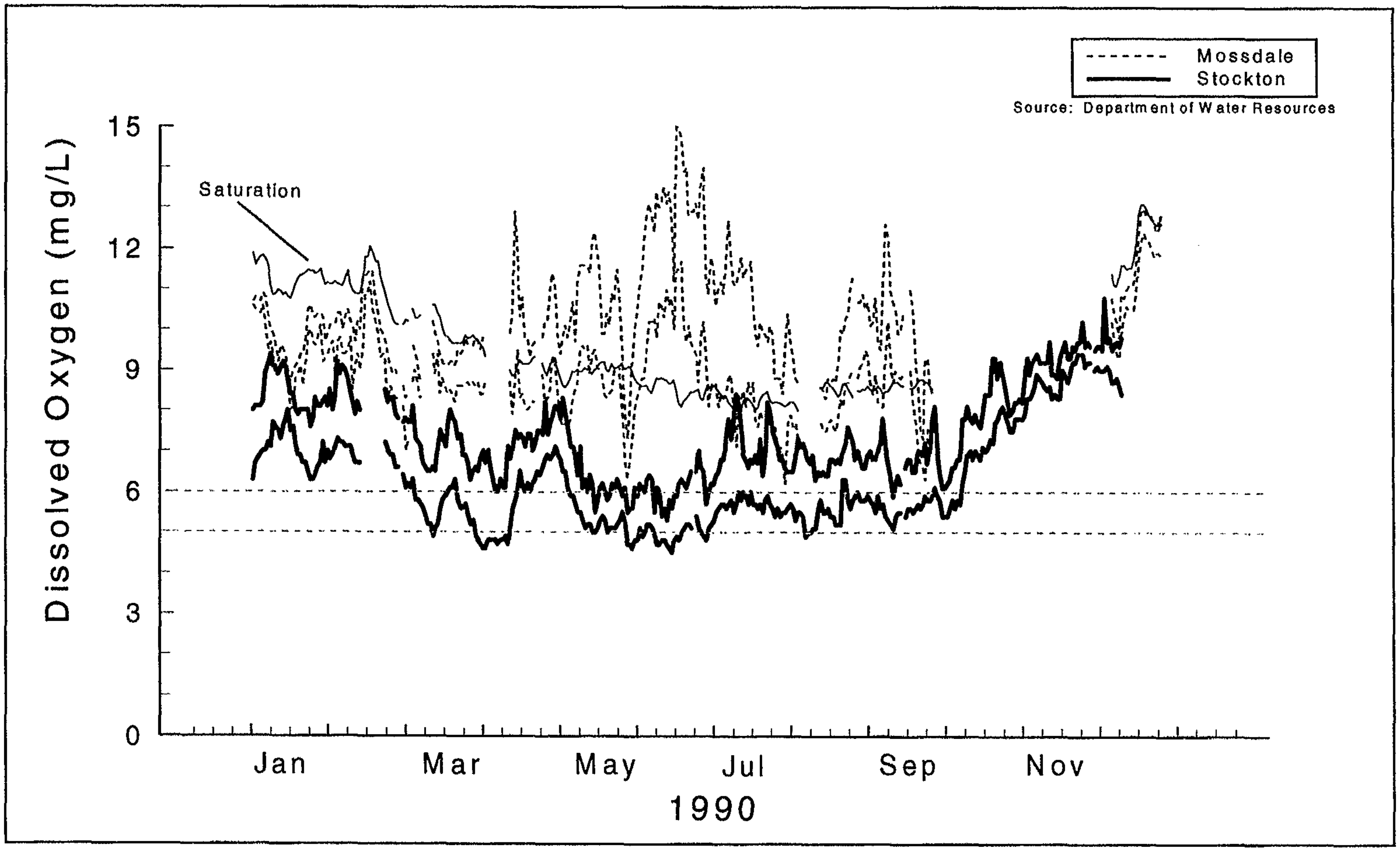
Jones & Stokes Associates, Inc.

Figure 12d
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel



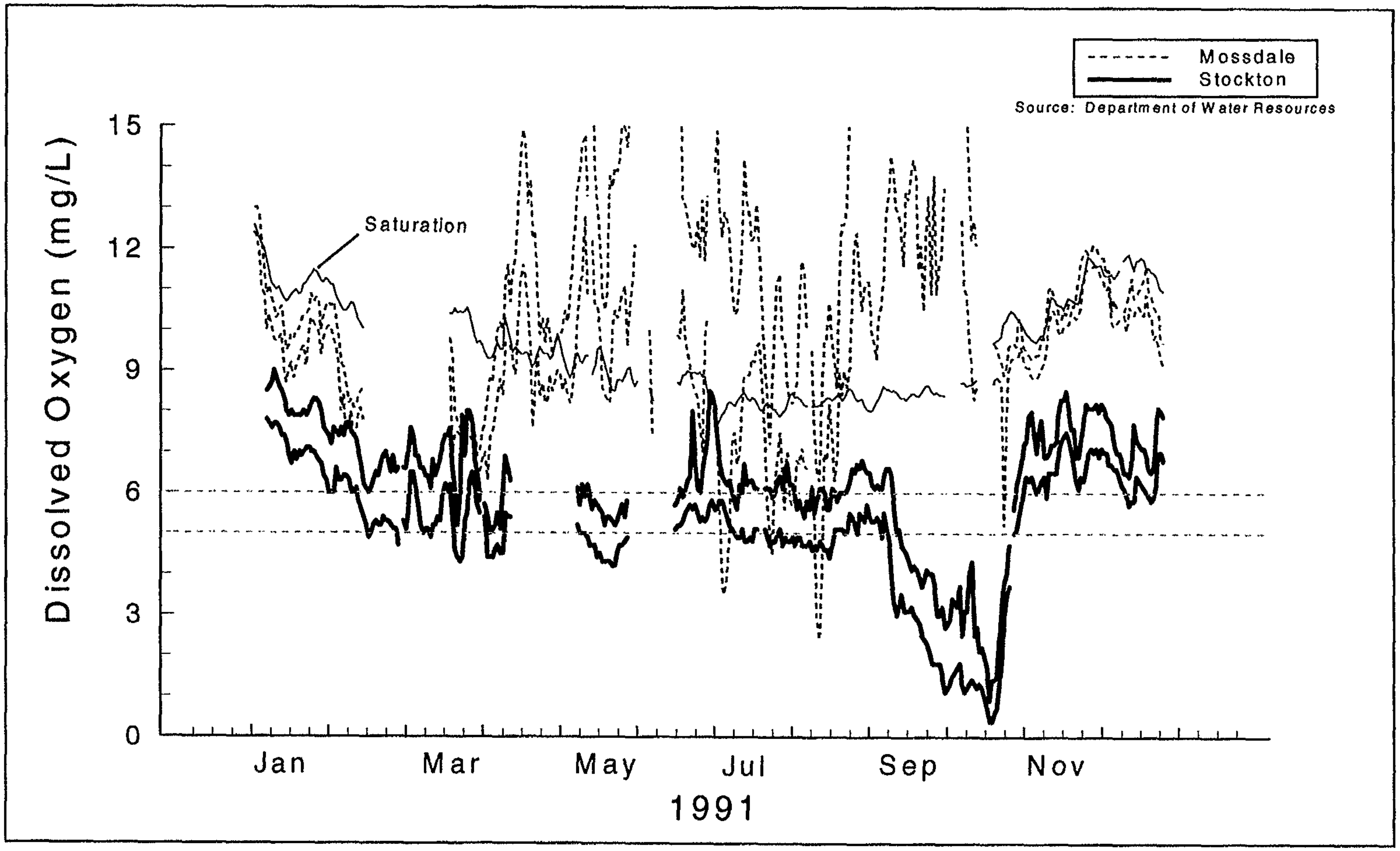
Jones & Stokes Associates, Inc.

Figure 12e
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel



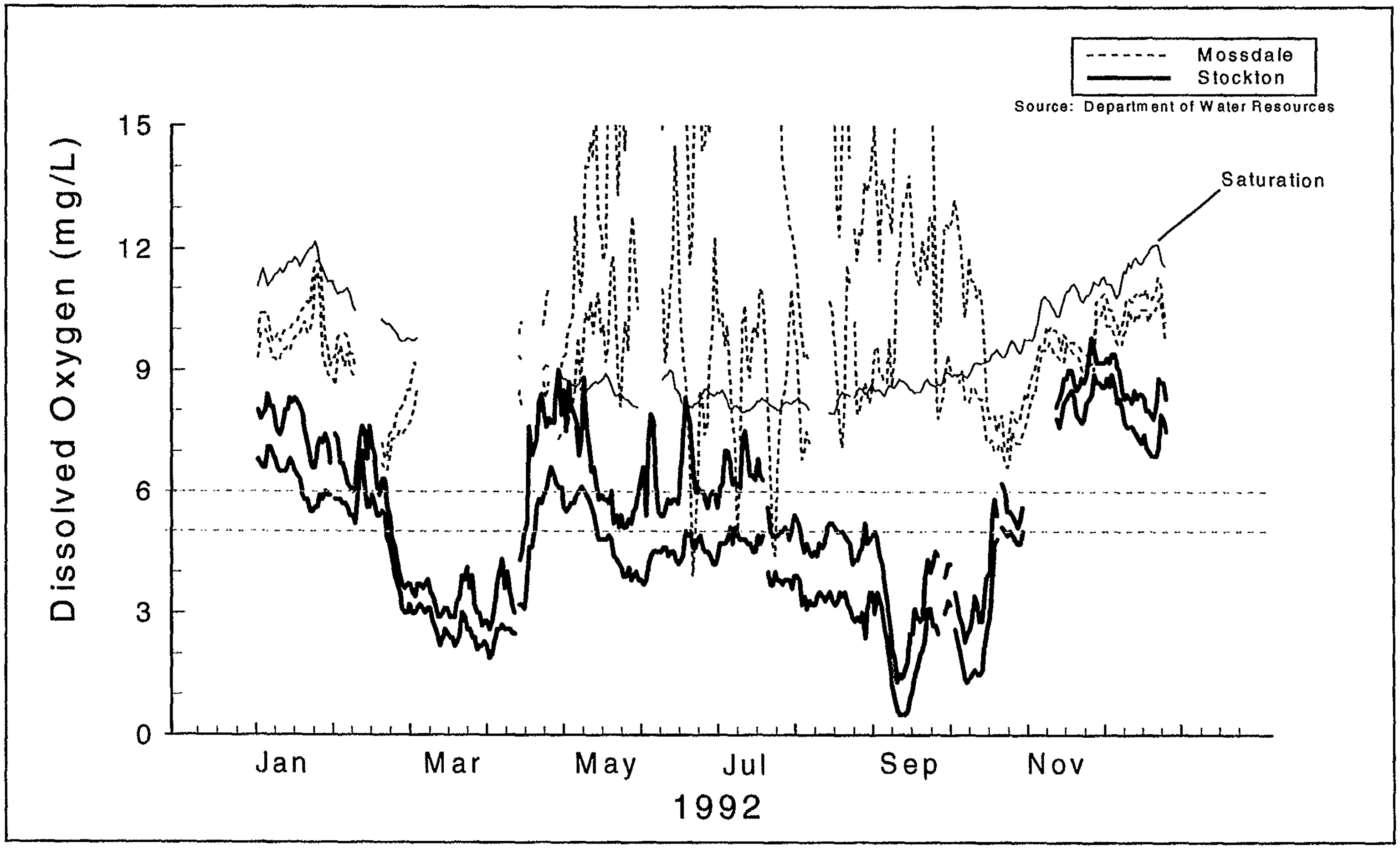
Jones & Stokes Associates, Inc.

Figure 12f
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel



Jones & Stokes Associates, Inc.

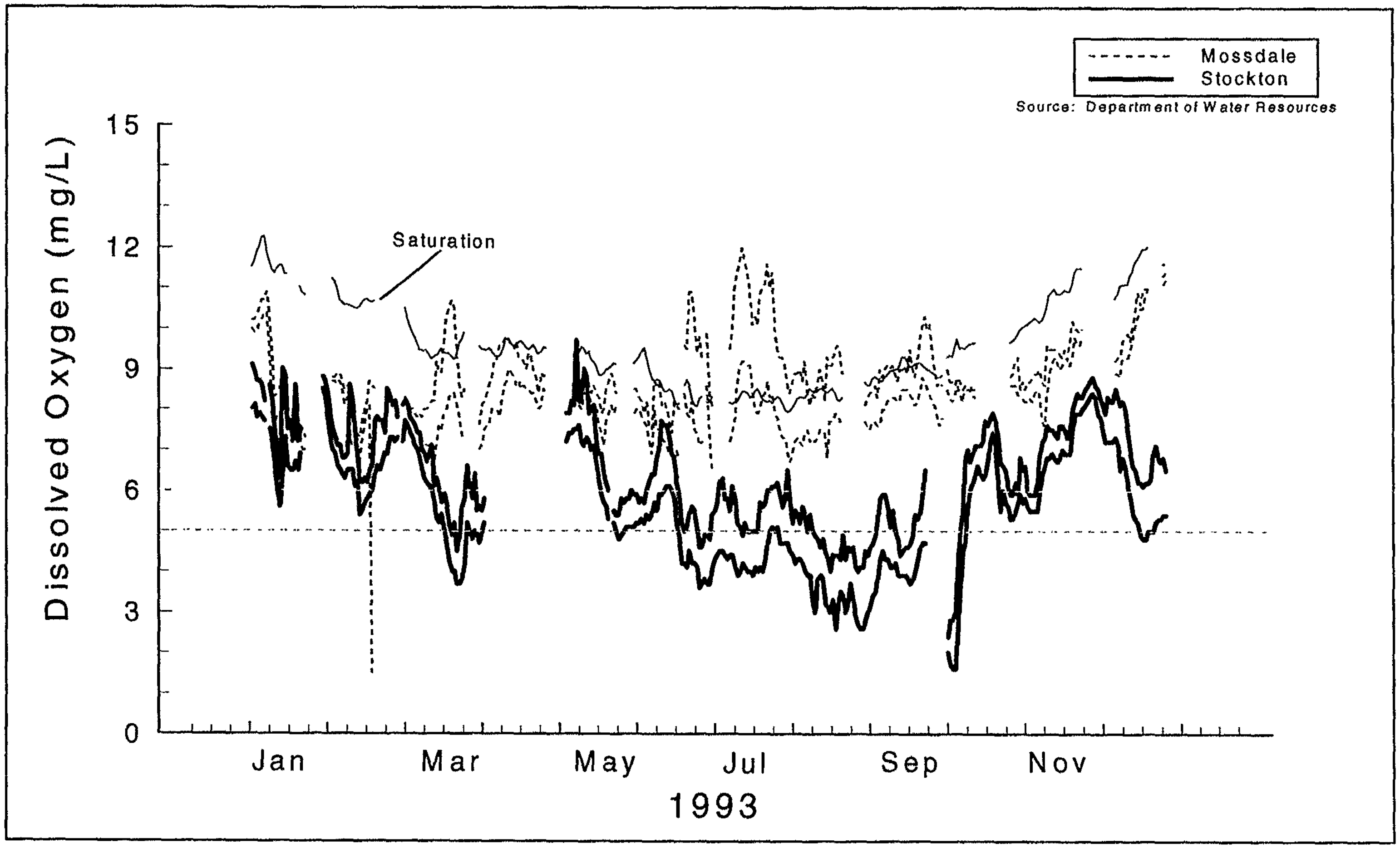
Figure 12g
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel



Jones & Stokes Associates, Inc.

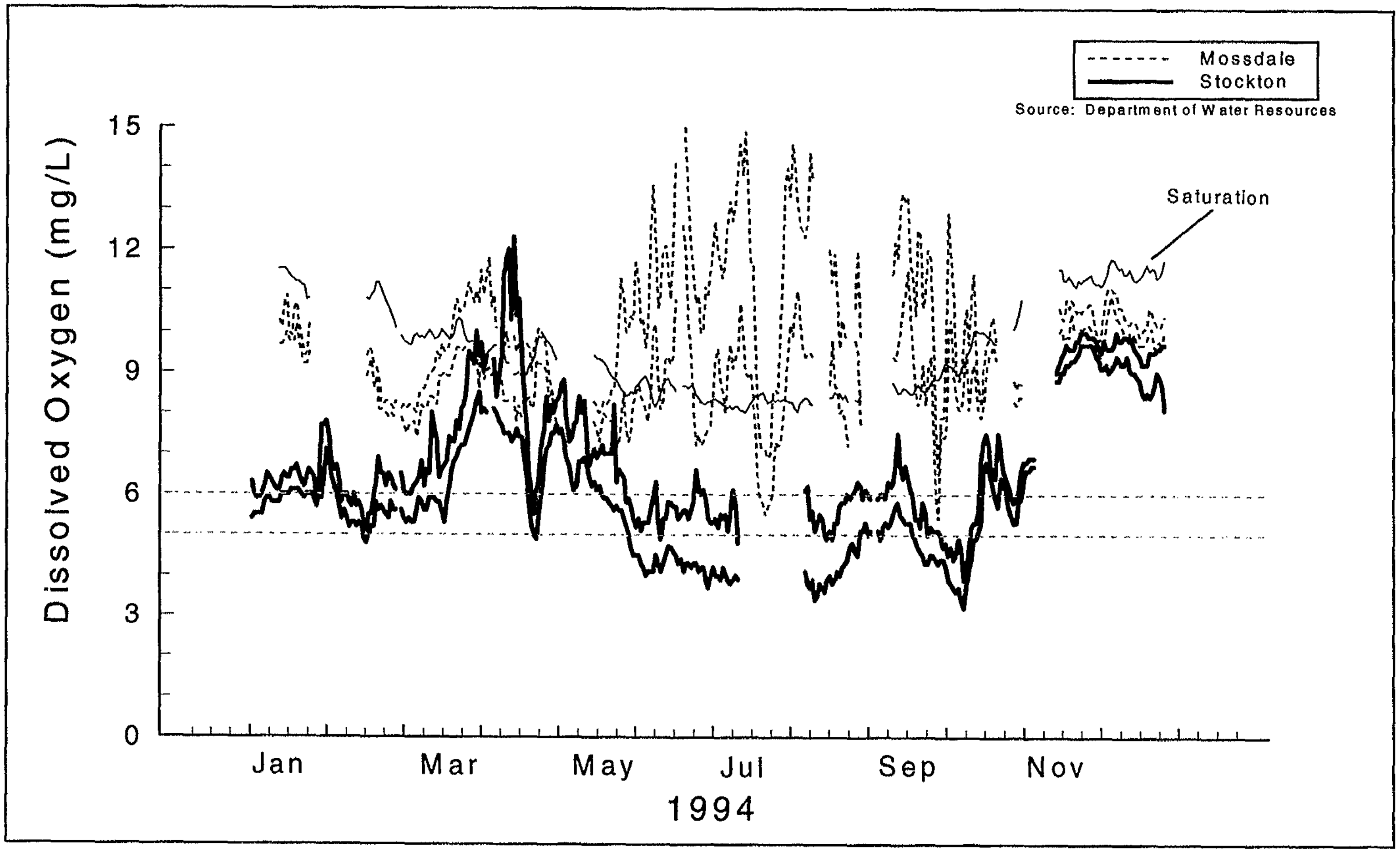
Figure 12h
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel

D-041977



Jones & Stokes Associates, Inc.

Figure 12i
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel

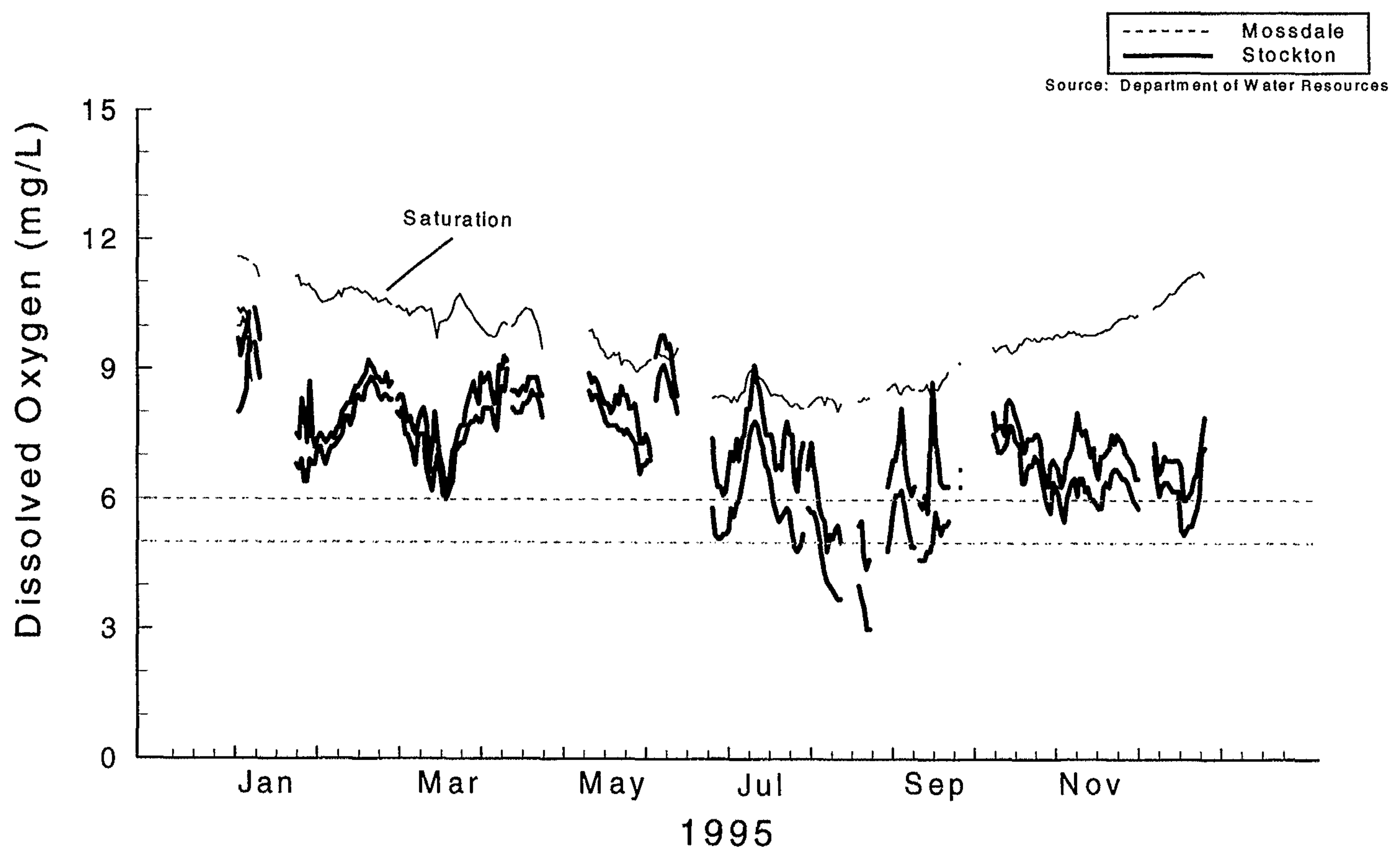


Jones & Stokes Associates, Inc.

Figure 12j
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel

D-041979

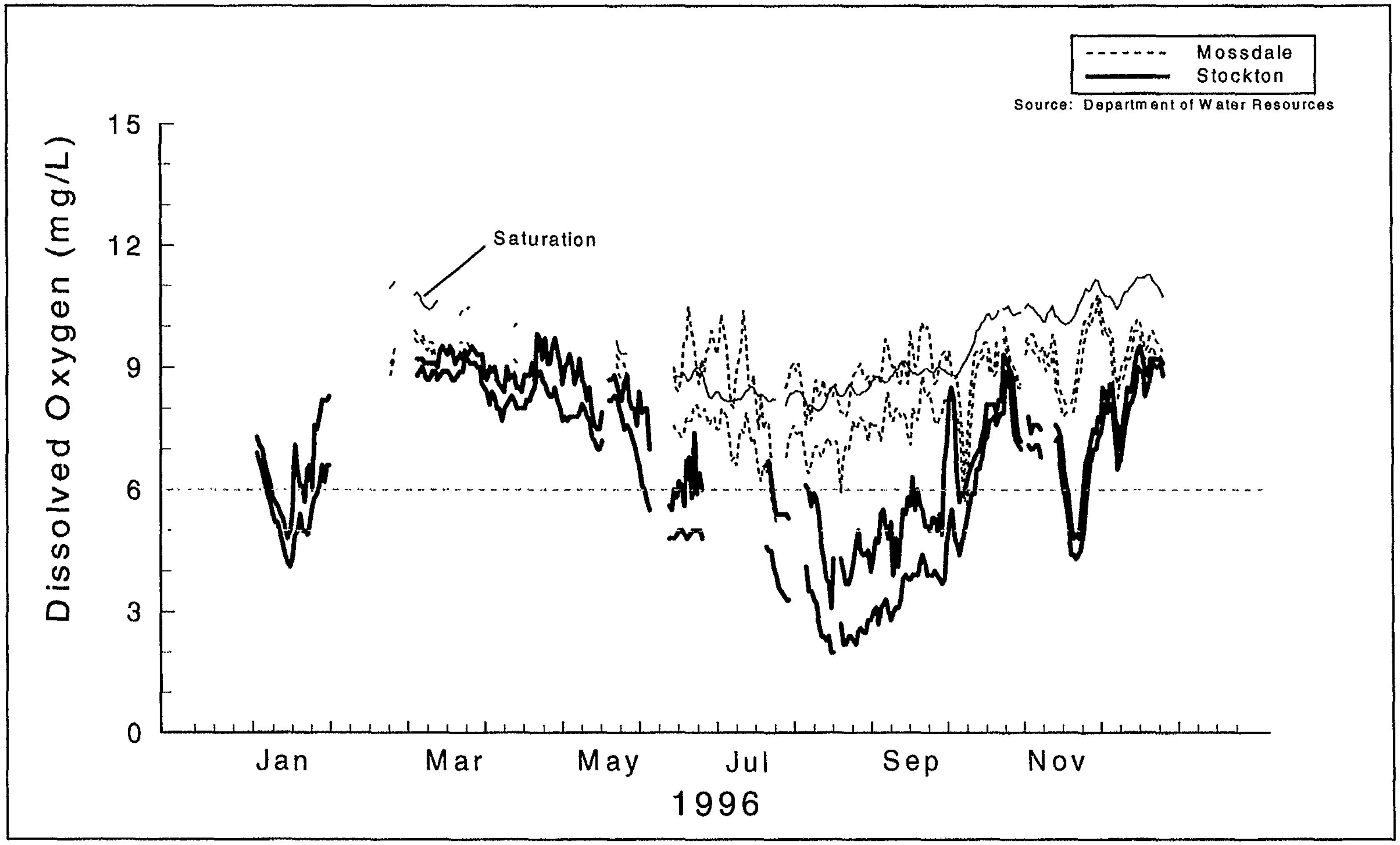
D-041980



D-041980

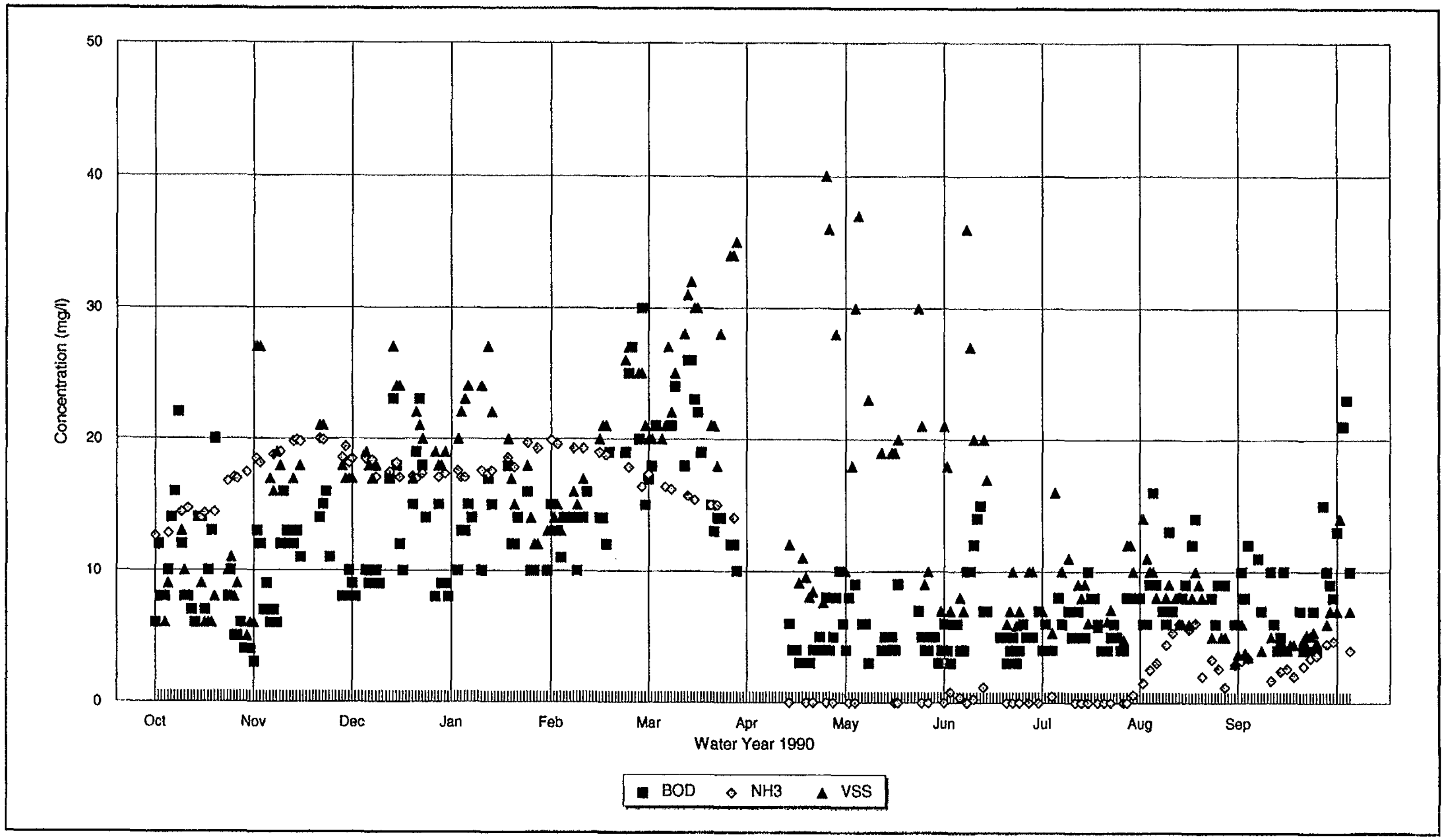
Jones & Stokes Associates, Inc.

Figure 12k
Minimum and Maximum Dissolved Oxygen Concentration in the Stockton Ship Channel (no data for Mossdale)



Jones & Stokes Associates, Inc.

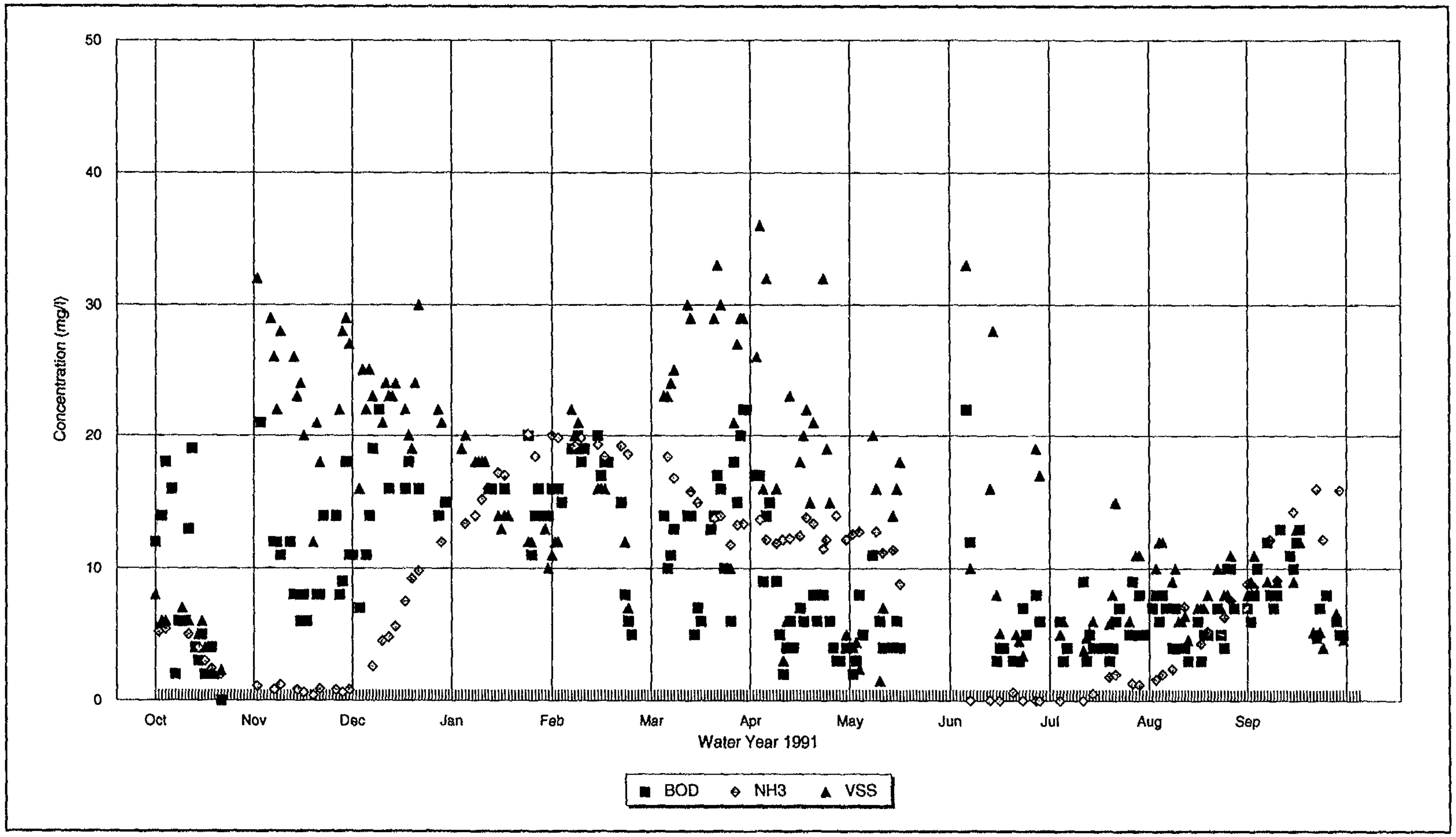
Figure 12l
Minimum and Maximum Dissolved Oxygen Concentration in the San Joaquin River at Mossdale and in the Stockton Ship Channel



Jones & Stokes Associates, Inc.

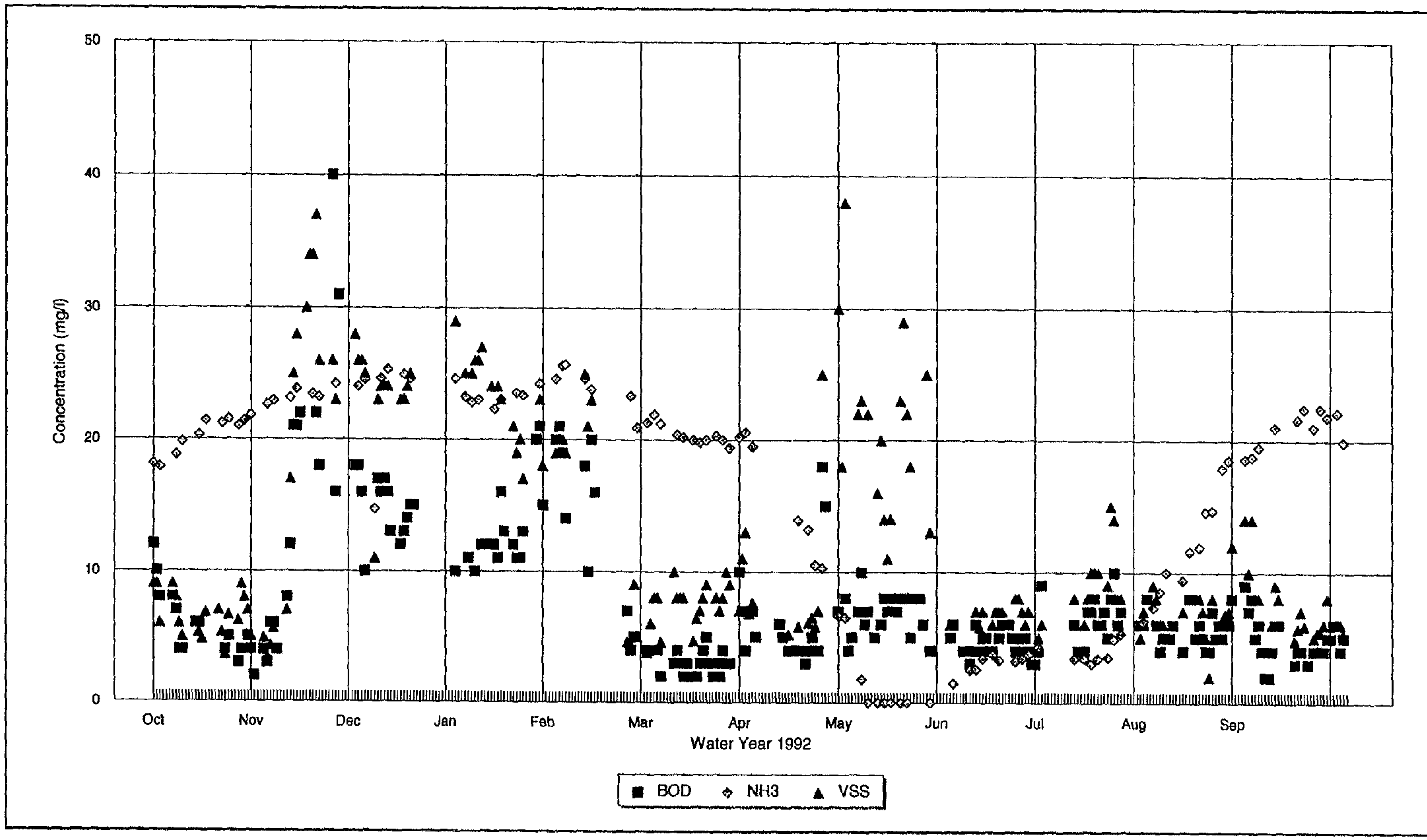
Figure 13a
Stockton RWCF Effluent Concentrations of Biochemical Oxygen Demand, Ammonia-N, and Volatile Suspended Solids for 1990

D—041982



Jones & Stokes Associates, Inc.

Figure 13b
Stockton RWCF Effluent Concentrations of Biochemical Oxygen Demand, Ammonia-N, and Volatile Suspended Solids for 1991

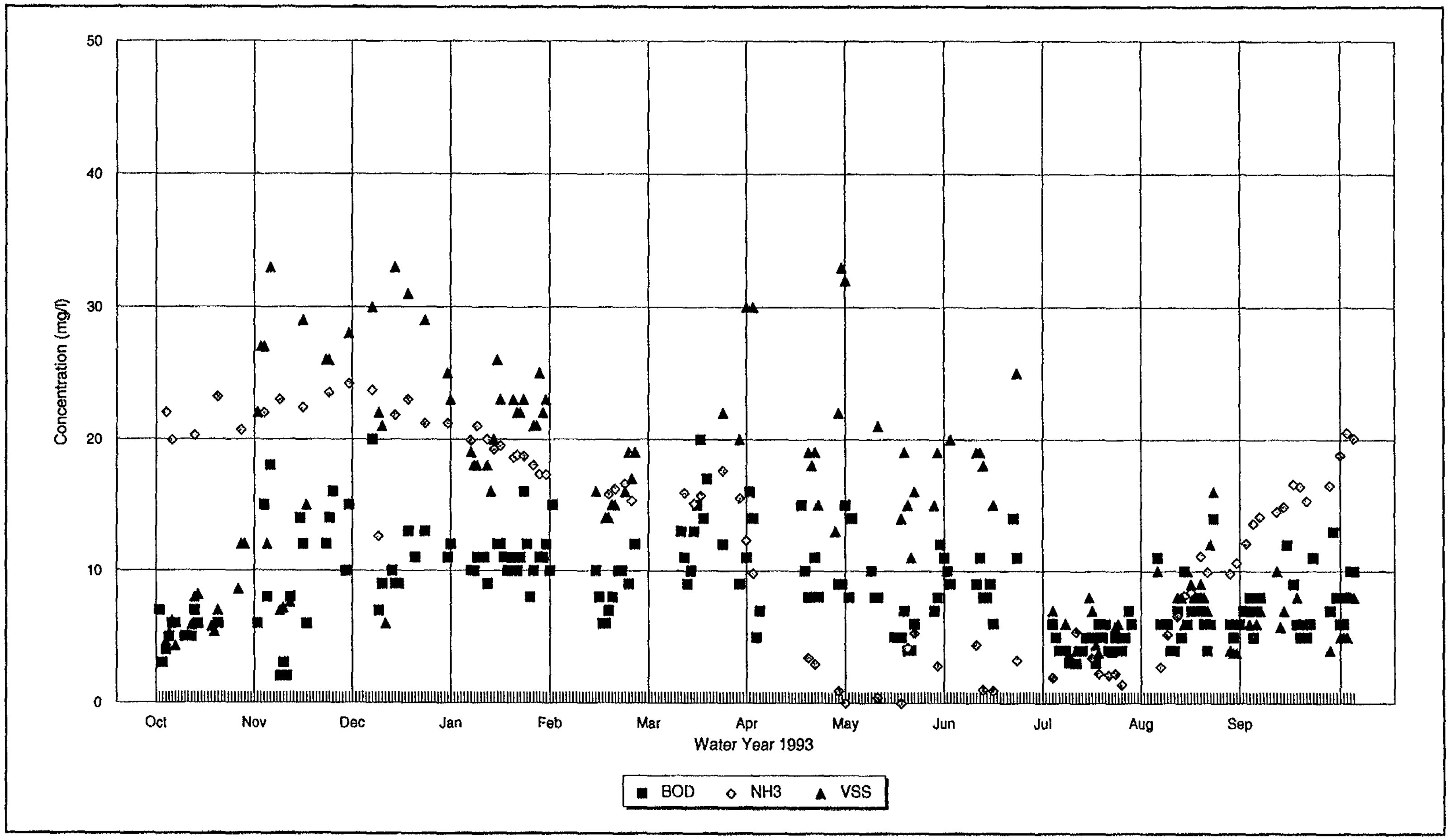


Jones & Stokes Associates, Inc.

Figure 13c
Stockton RWCF Effluent Concentrations of Biochemical Oxygen Demand, Ammonia-N, and Volatile Suspended Solids for 1992

D-041984

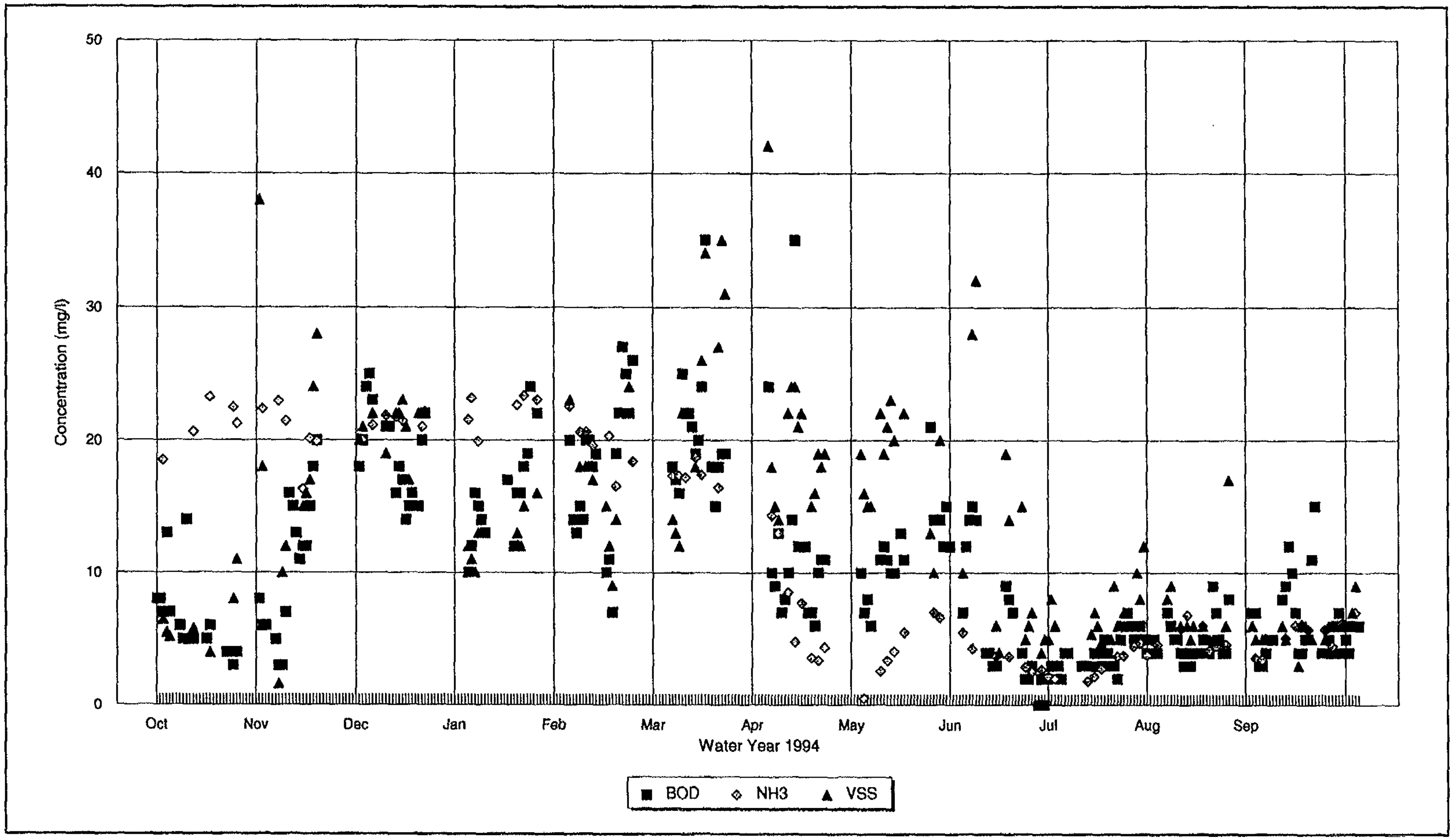
D-041984



Jones & Stokes Associates, Inc.

Figure 13d
Stockton RWCF Effluent Concentrations of Biochemical Oxygen Demand, Ammonia-N, and Volatile Suspended Solids for 1993

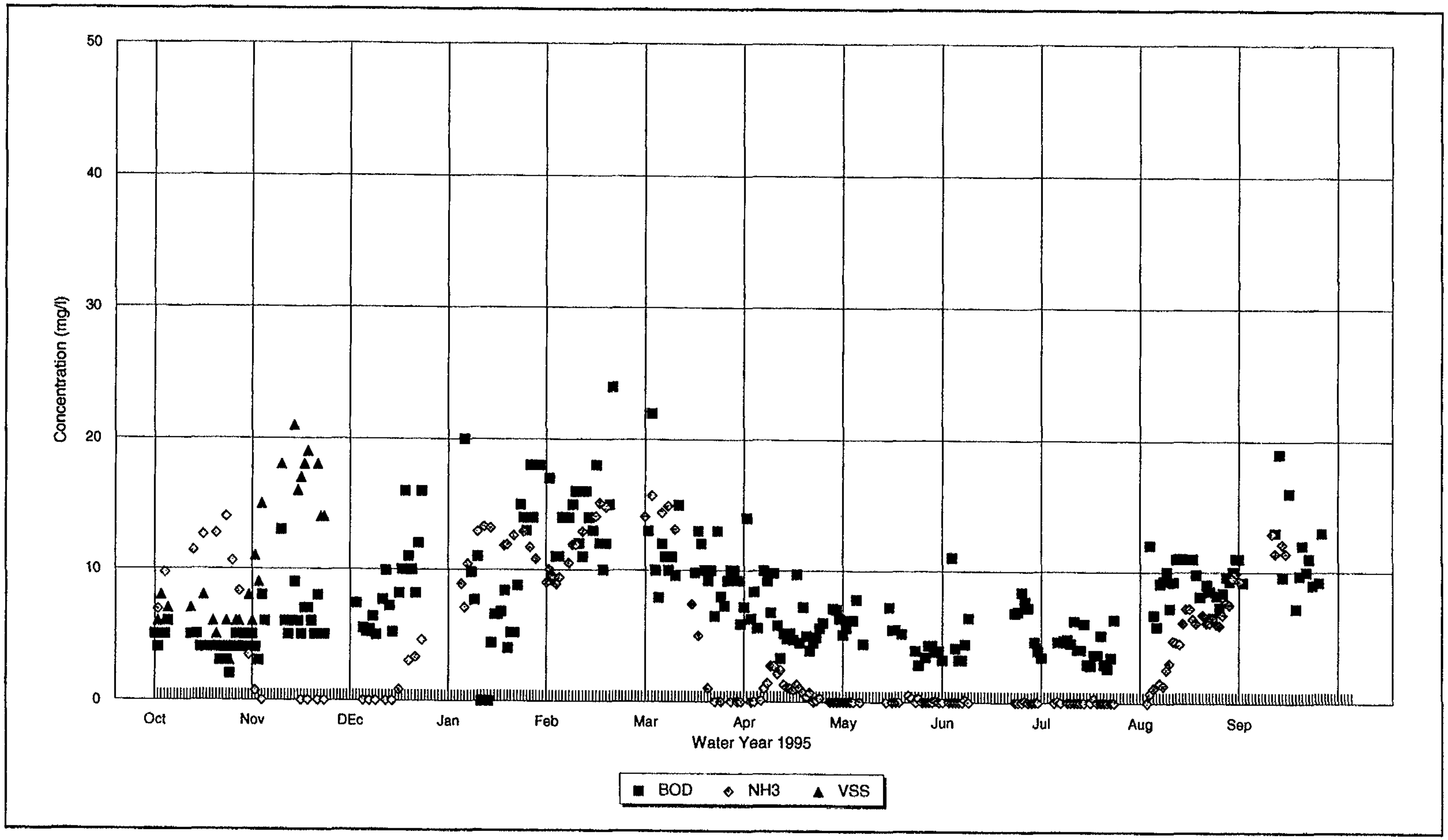
D-041986



D — 0 4 1 9 8 6

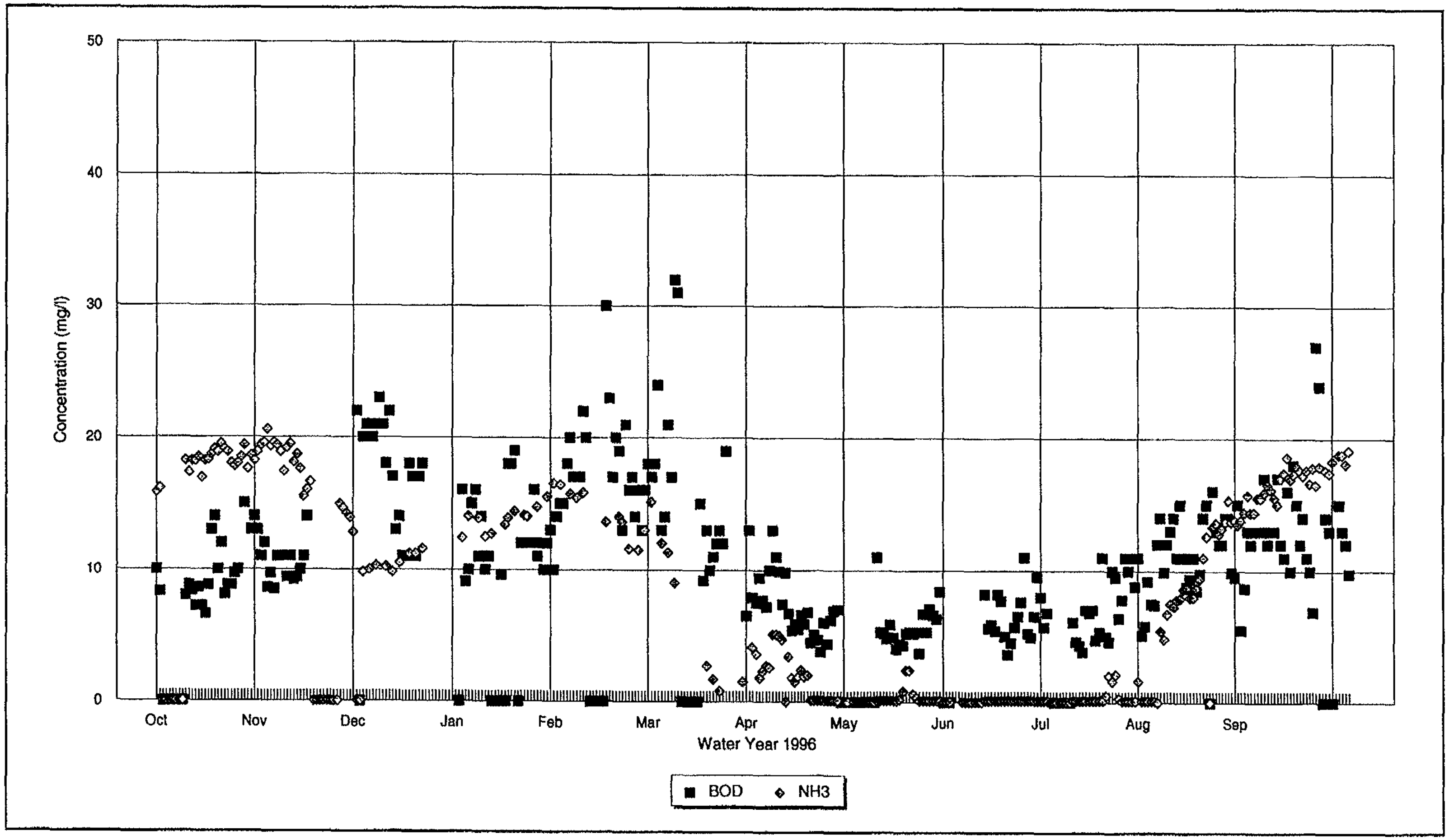
Jones & Stokes Associates, Inc.

Figure 13e
Stockton RWCF Effluent Concentrations of Biochemical Oxygen Demand, Ammonia-N, and Volatile Suspended Solids for 1994



Jones & Stokes Associates, Inc.

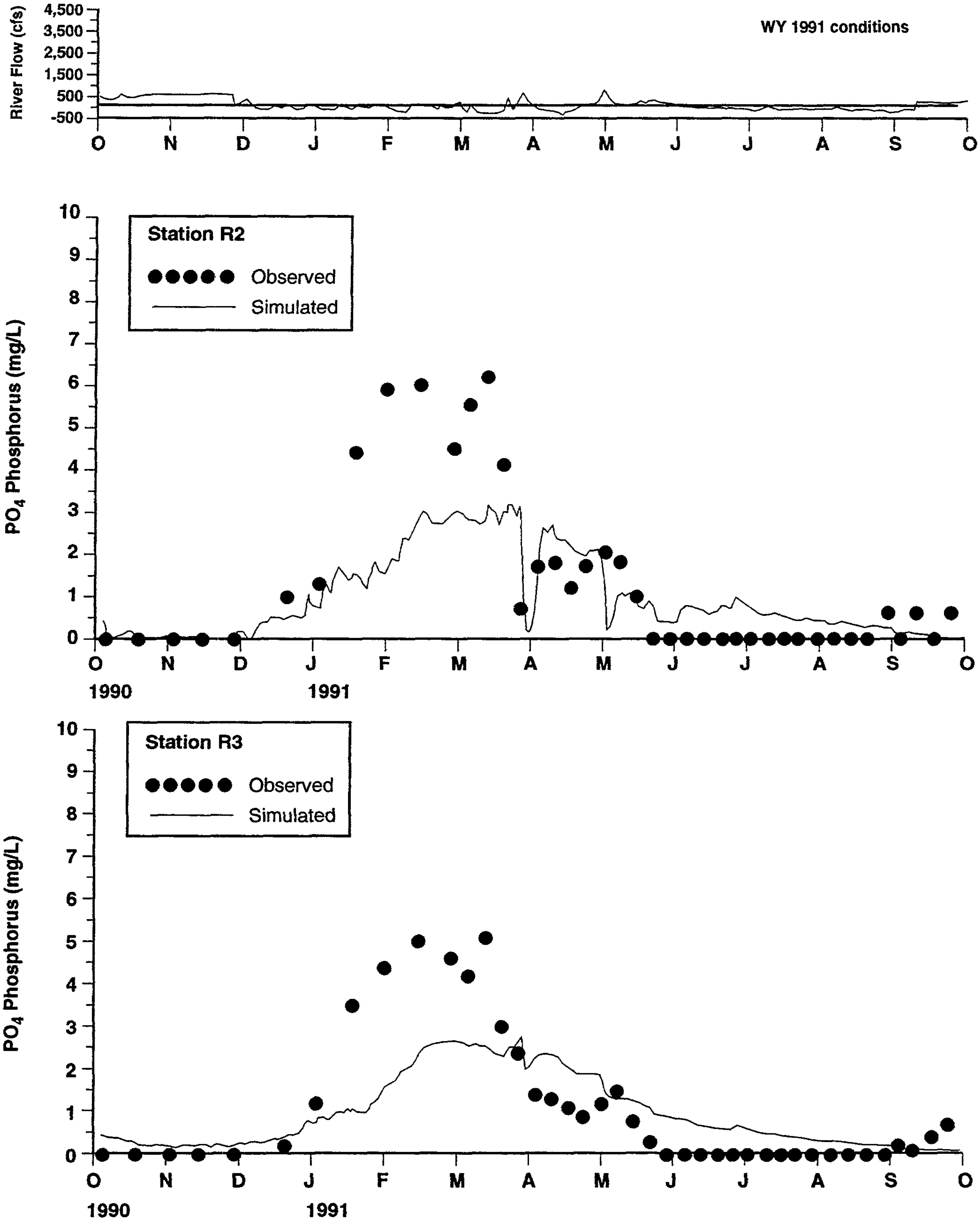
Figure 13f
Stockton RWCF Effluent Concentrations of Biochemical Oxygen Demand, Ammonia-N, and Volatile Suspended Solids for 1995



Jones & Stokes Associates, Inc.

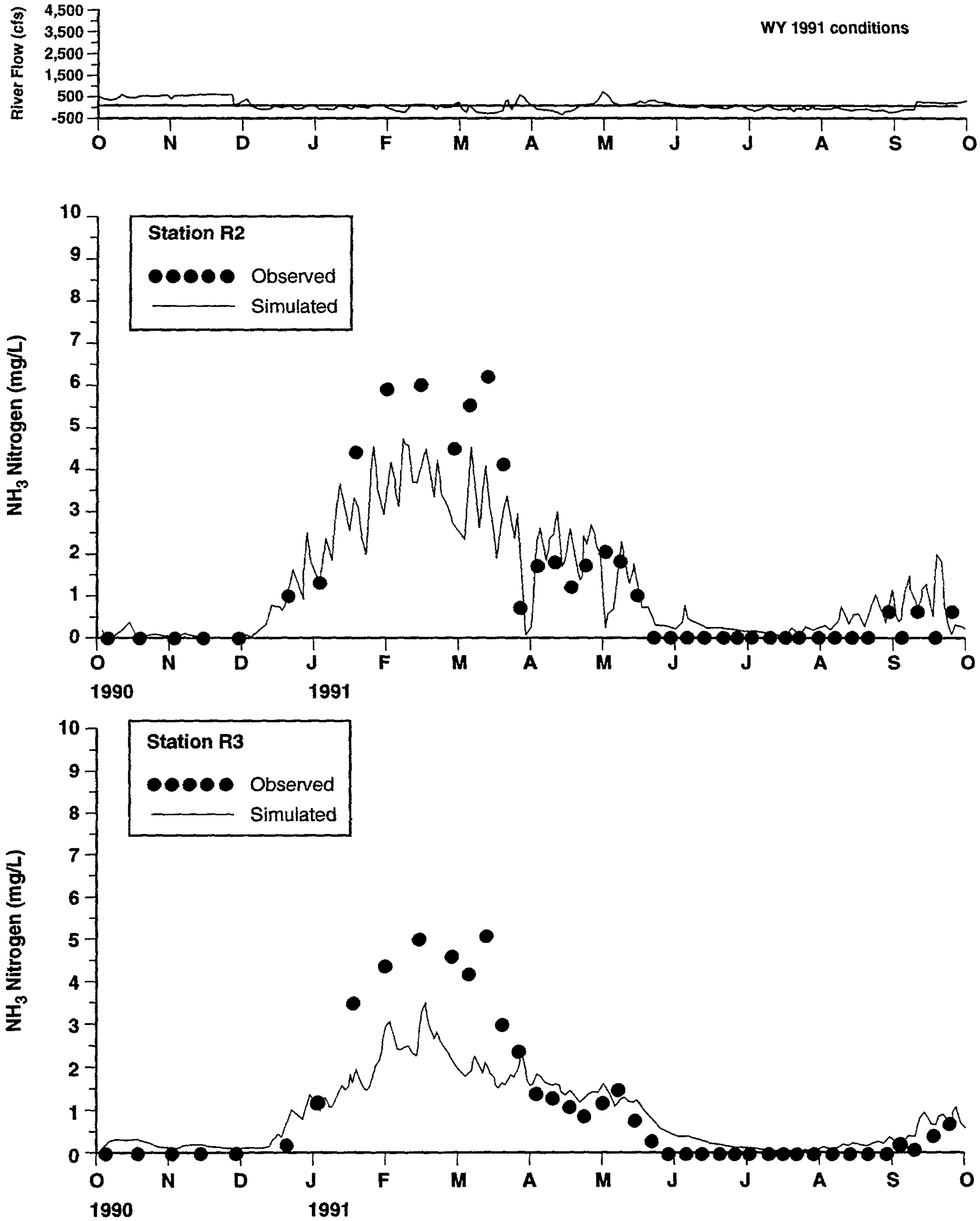
Figure 13g
Stockton RWCF Effluent Concentrations of Biochemical Oxygen Demand, Ammonia-N, and Volatile Suspended Solids for 1996

D-041988



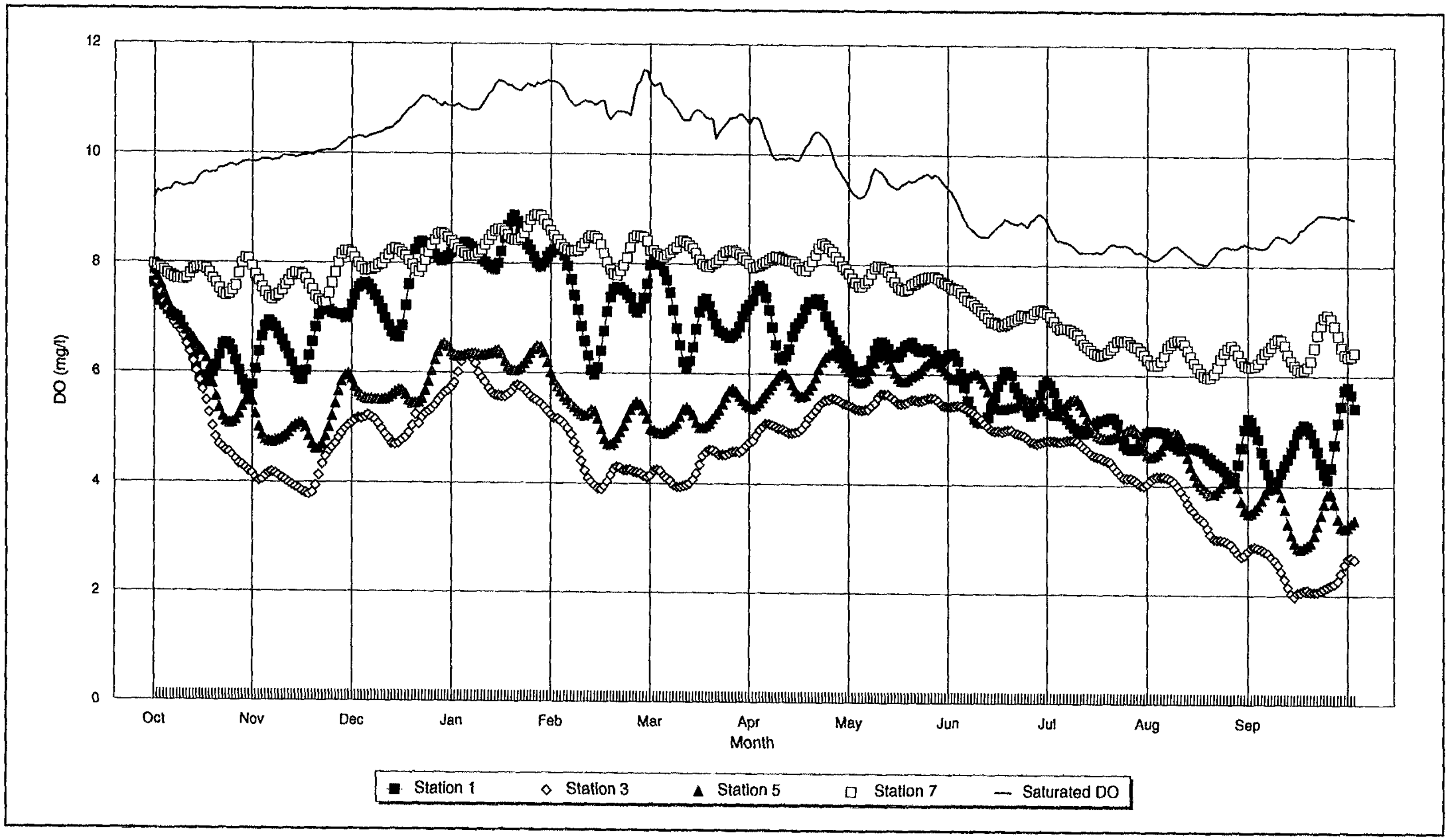
Jones & Stokes Associates, Inc.

Figure 14
Calibration of Tidal and Net Flows Using Phosphorus Concentrations at Station R2 (Upstream) and Station R3 (Downstream)



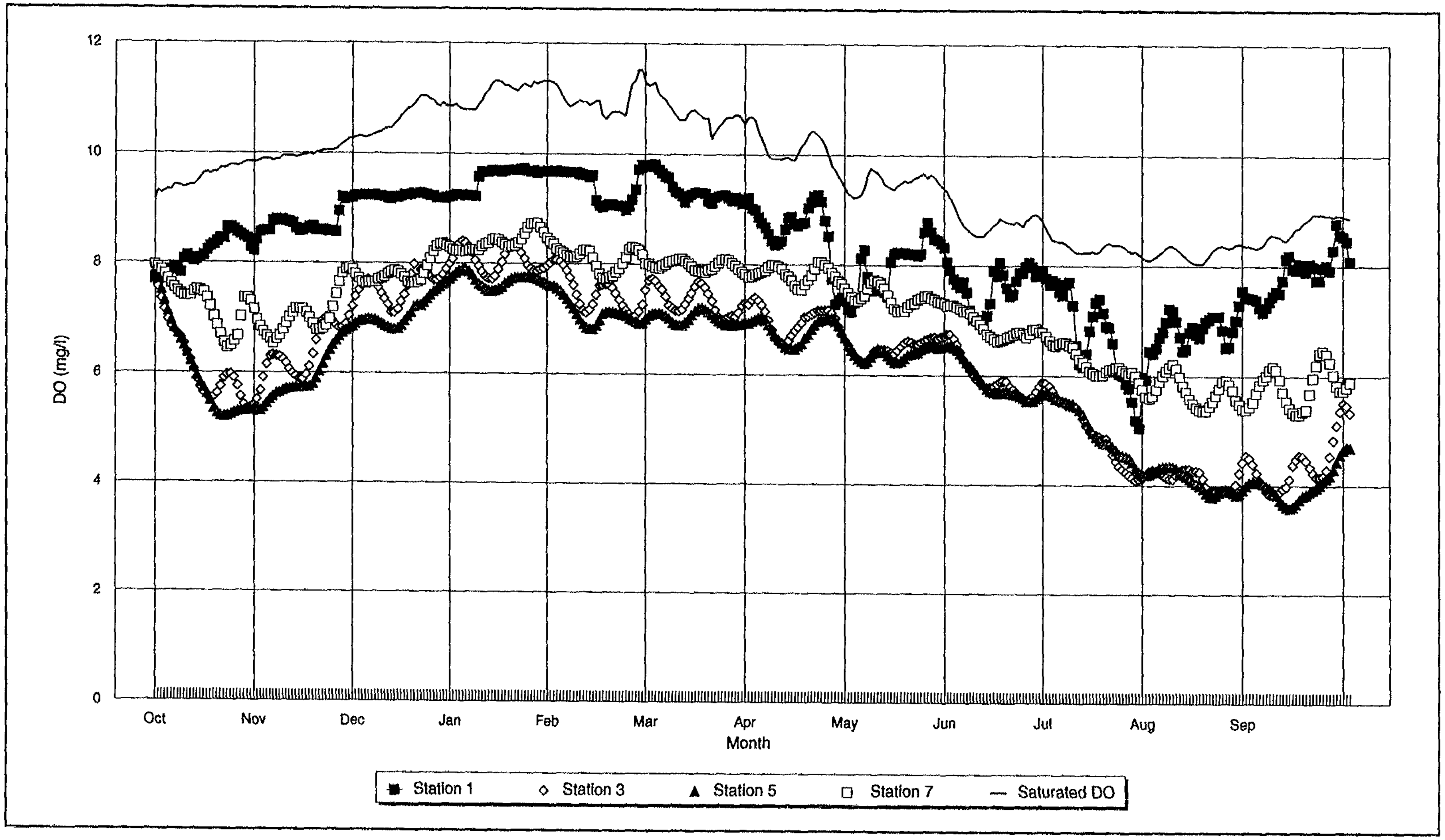
Jones & Stokes Associates, Inc.

Figure 15
Calibration of Tidal and Net Flows Using Ammonia Concentrations at Station R2 (Upstream) and Station R3 (Downstream)



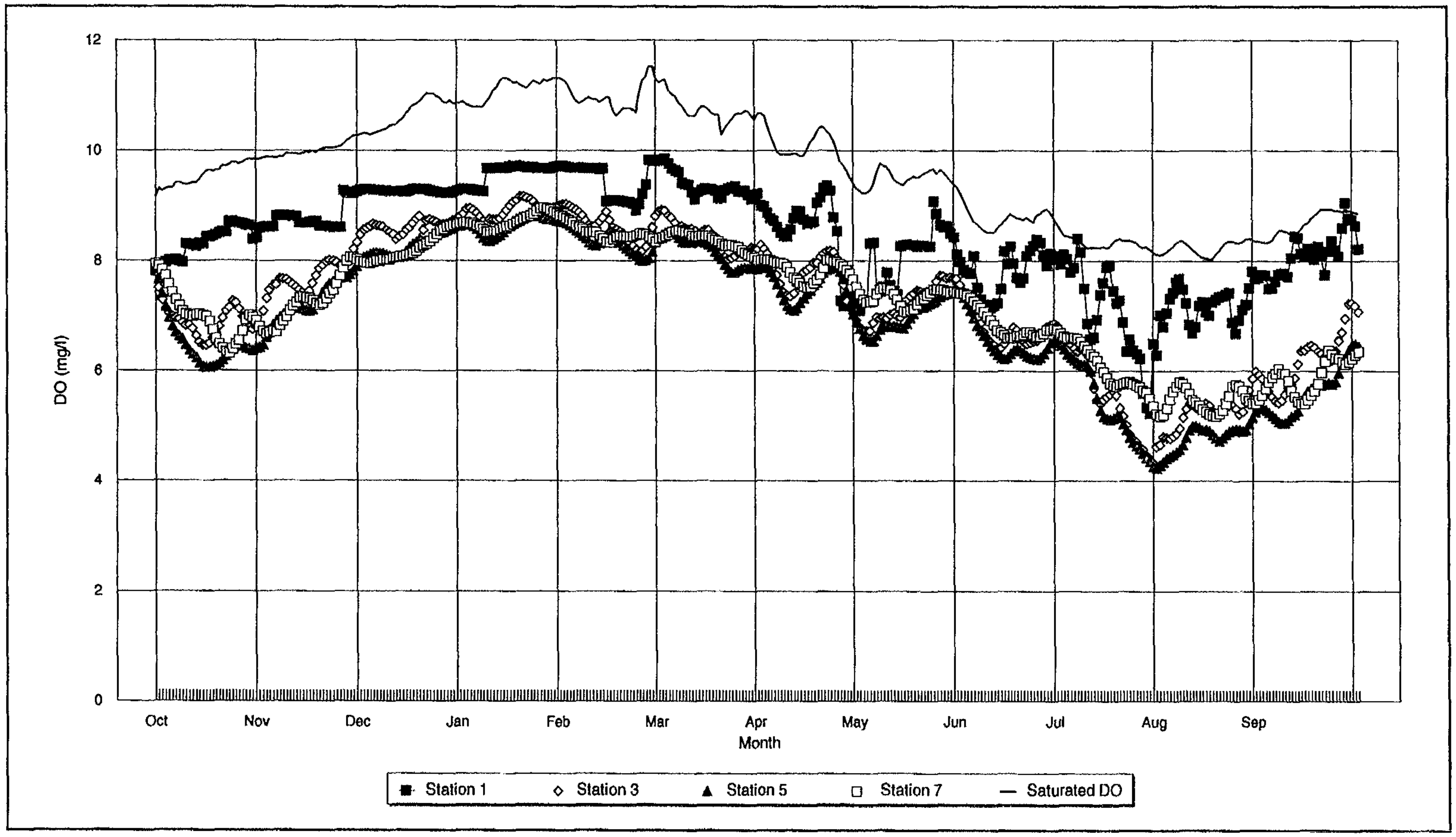
Jones & Stokes Associates, Inc.

Figure 16
Simulated San Joaquin River Dissolved Oxygen Concentrations for 1996 RWCF Discharge with Net Flow of 0 cfs



Jones & Stokes Associates, Inc.

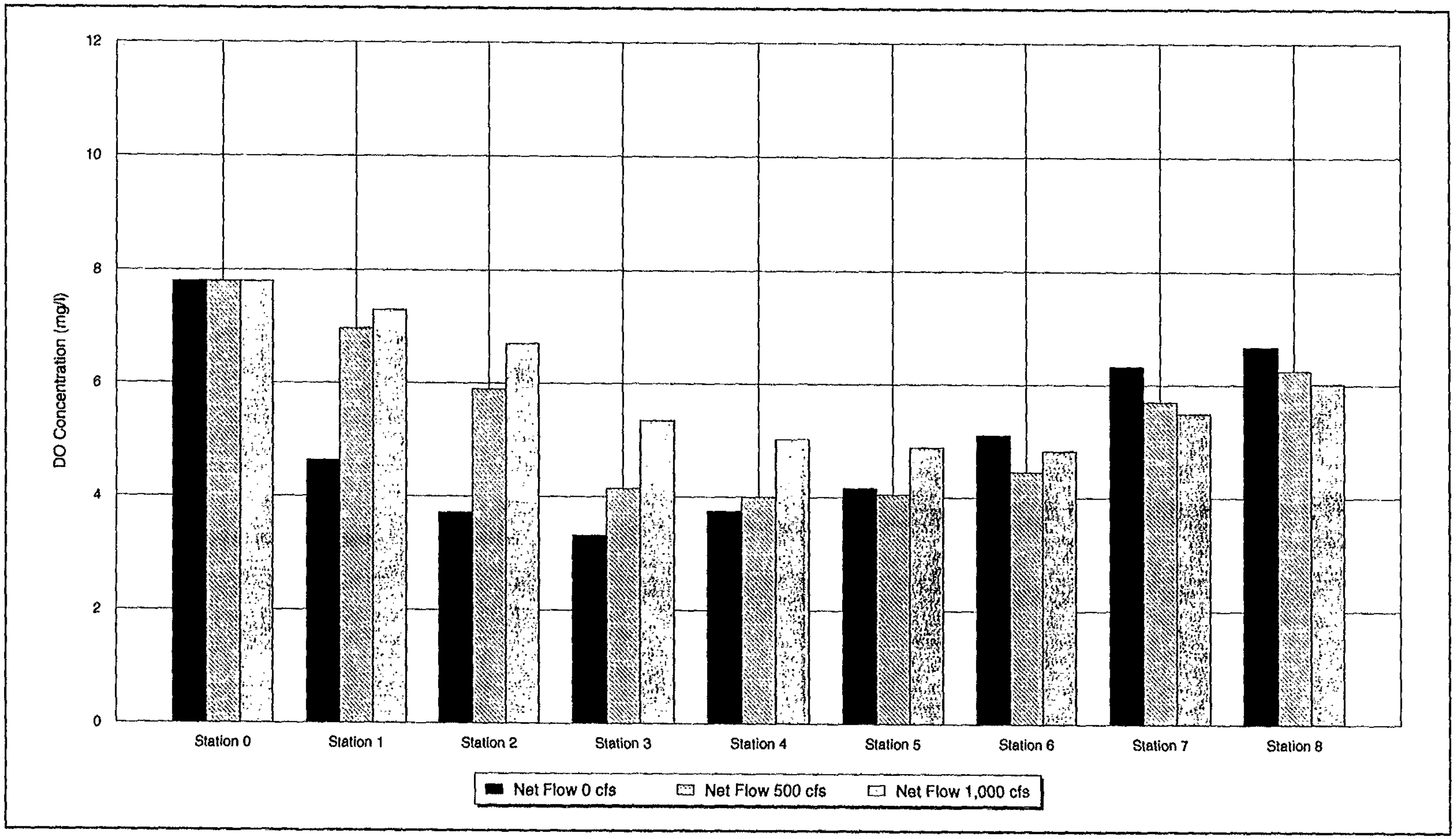
Figure 17
Simulated San Joaquin River Dissolved Oxygen Concentrations for 1996 RWCF Discharge with Net Flow of 500 cfs



Jones & Stokes Associates, Inc.

Figure 18
Simulated San Joaquin River Dissolved Oxygen Concentrations for 1996 RWCF Discharge with Net Flow of 1,000 cfs

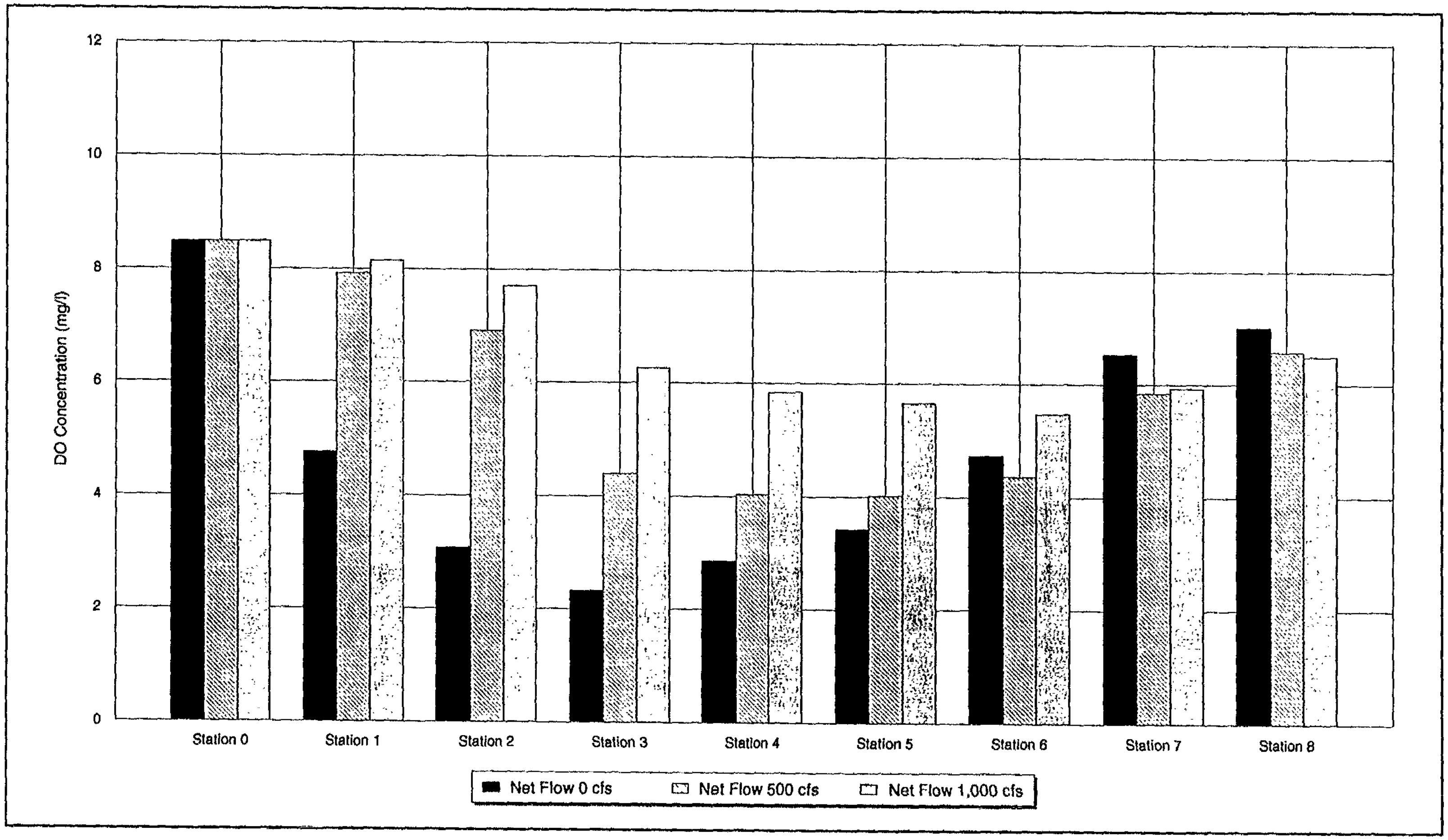
D-041994



Jones & Stokes Associates, Inc.

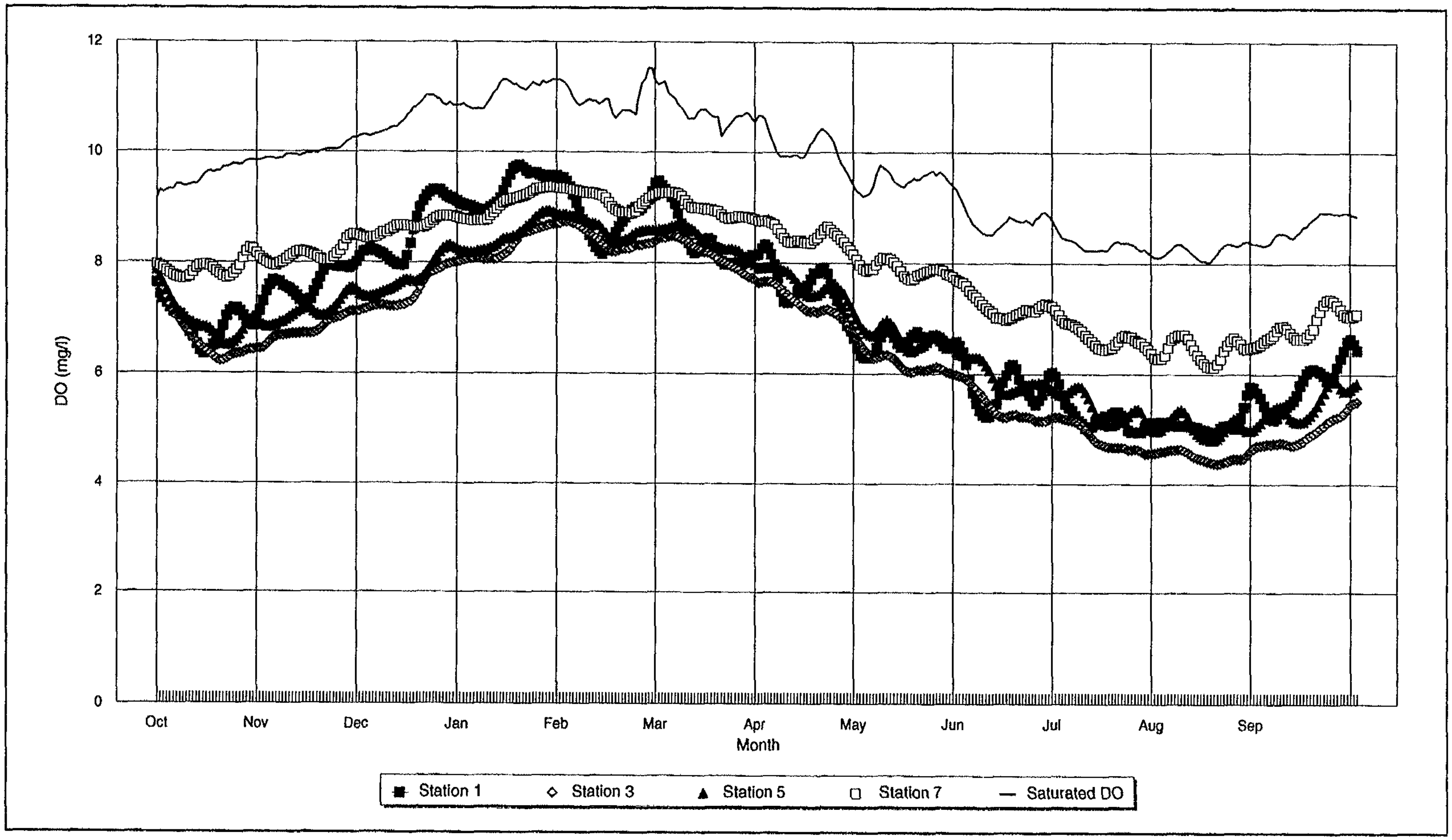
Figure 19
Average Simulated San Joaquin River Dissolved Oxygen Concentrations in August for 1996 RWCF Discharge at Net Flows of 0 cfs, 500 cfs, and 1,000 cfs

D—041994



Jones & Stokes Associates, Inc.

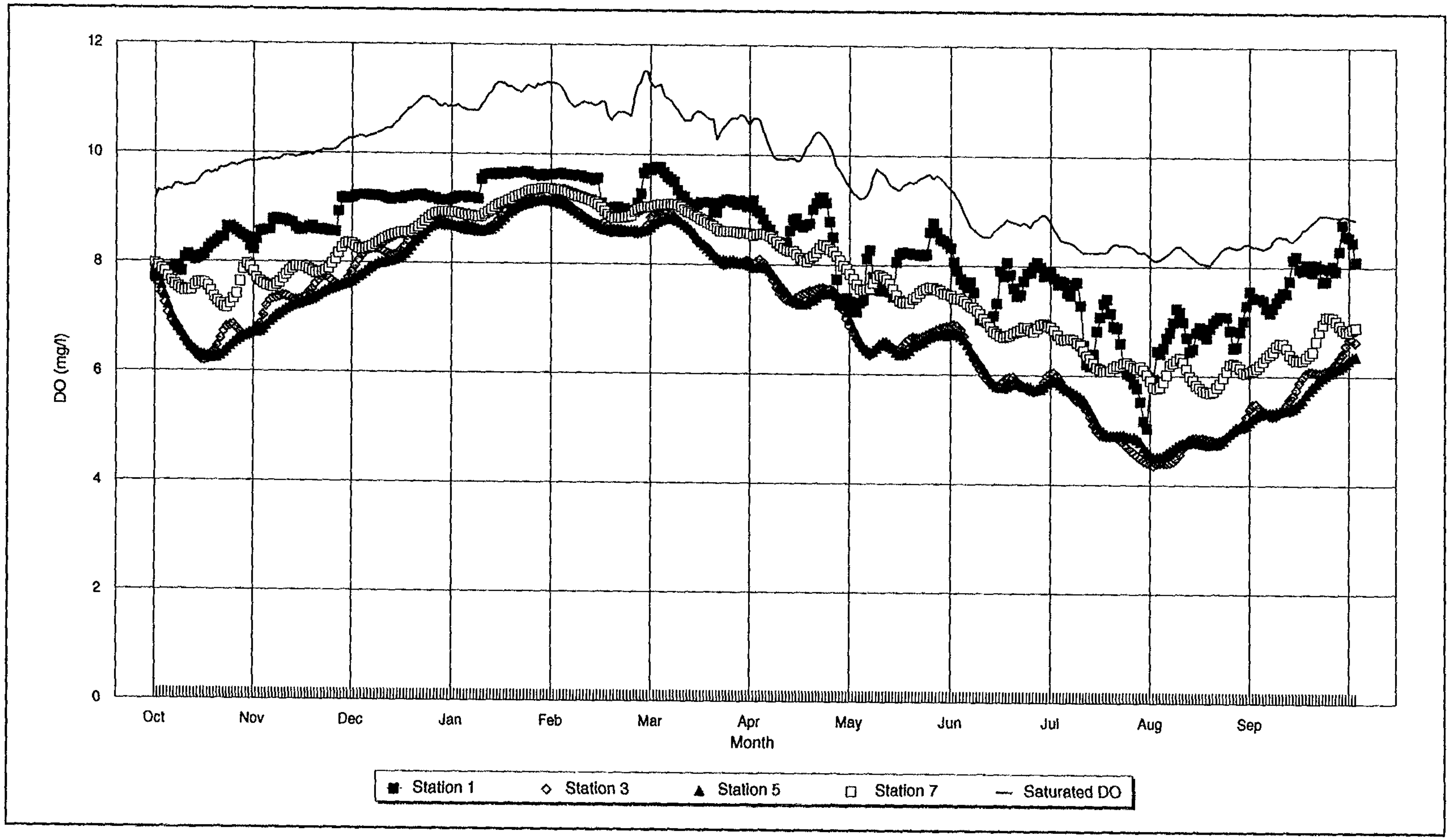
Figure 20
Average Simulated San Joaquin River Dissolved Oxygen Concentrations in September for 1996 RWCF Discharge at Net Flows of 0 cfs, 500 cfs, and 1,000 cfs



Jones & Stokes Associates, Inc.

Figure 21
Simulated San Joaquin River Dissolved Oxygen Concentrations for No RWCF Discharge with Net Flow of 0 cfs

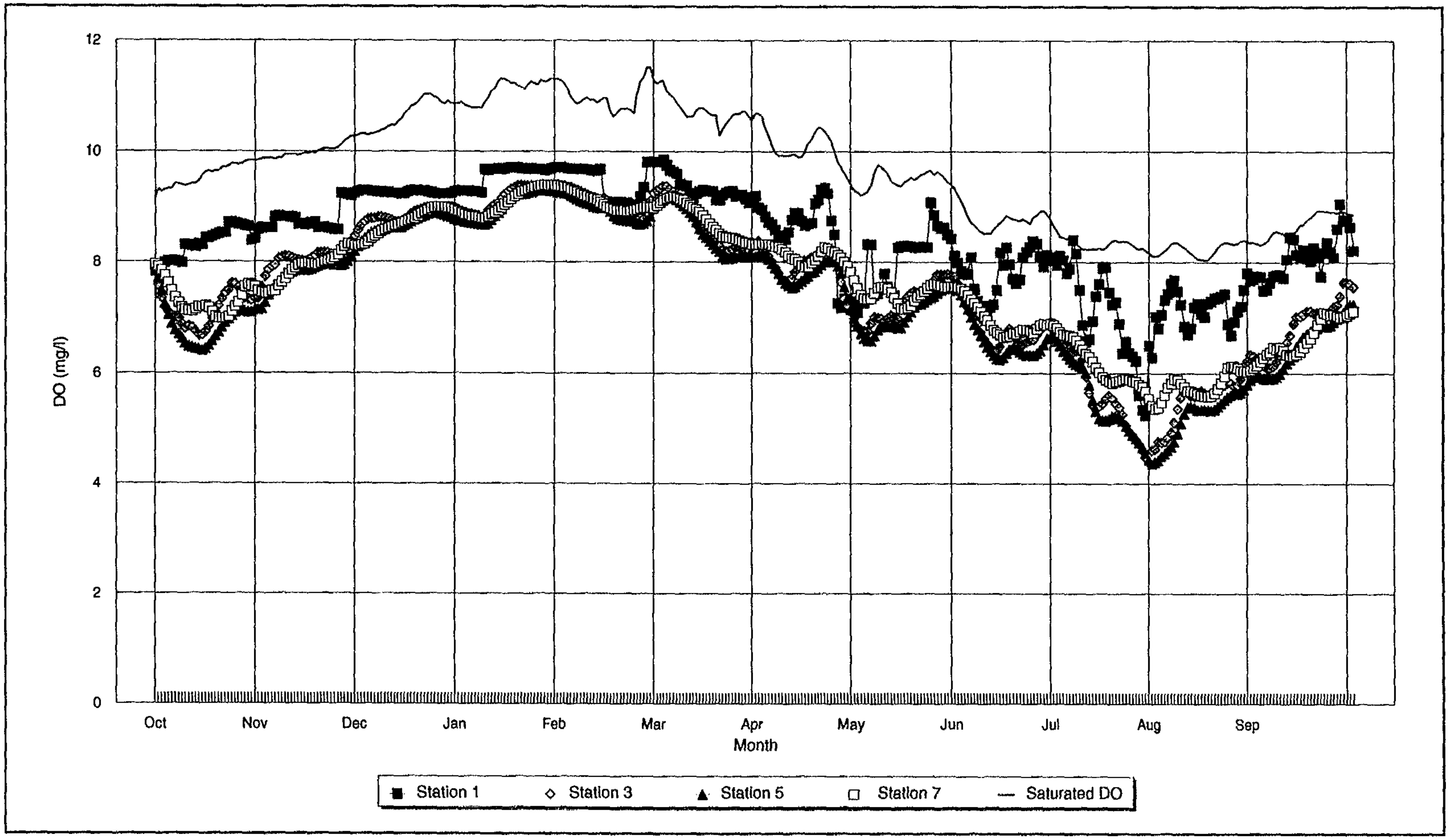
D-041997



Jones & Stokes Associates, Inc.

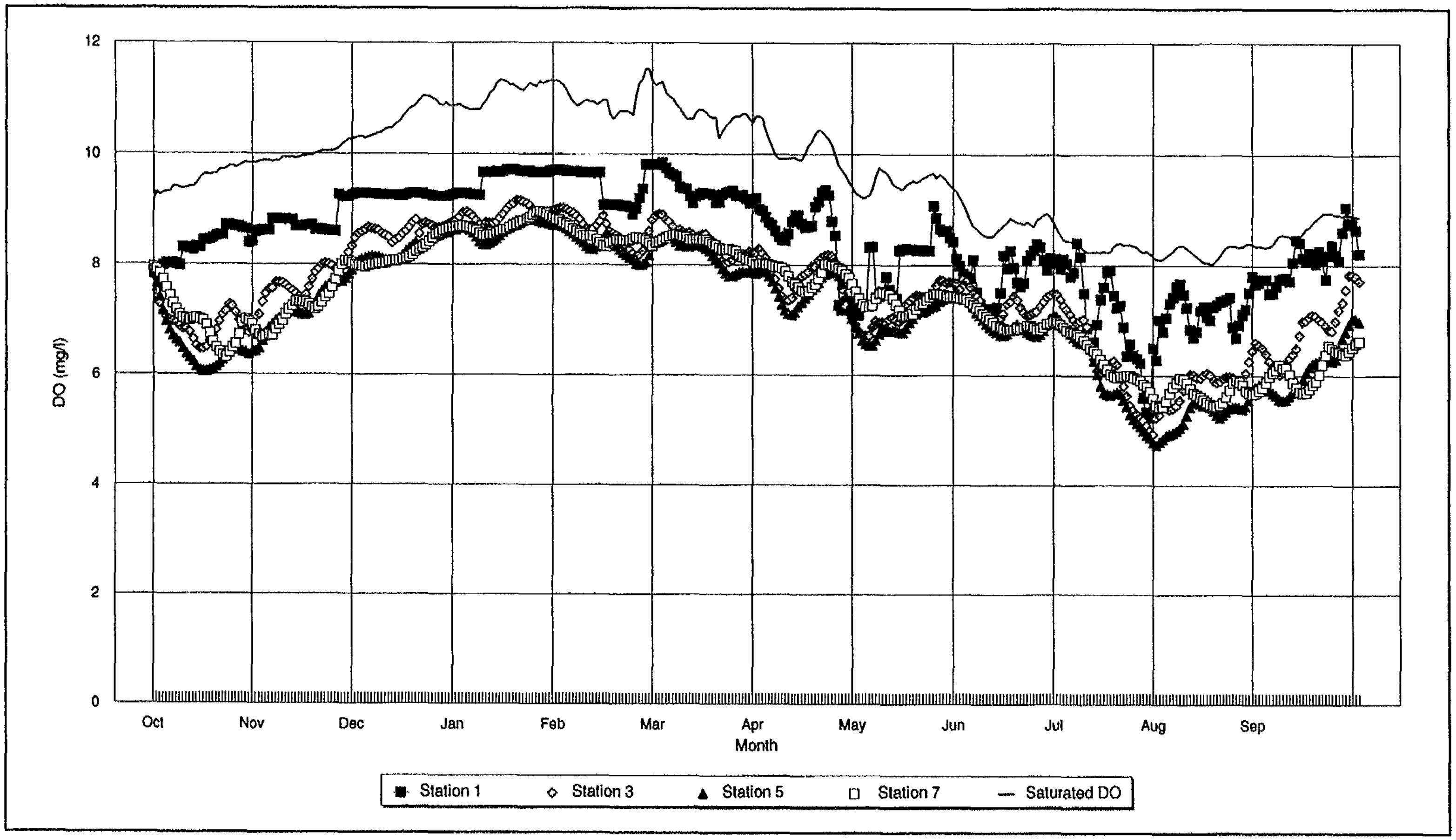
Figure 22
Simulated San Joaquin River Dissolved Oxygen Concentrations for No RWCF Discharge with Net Flow of 500 cfs

D-041997



Jones & Stokes Associates, Inc.

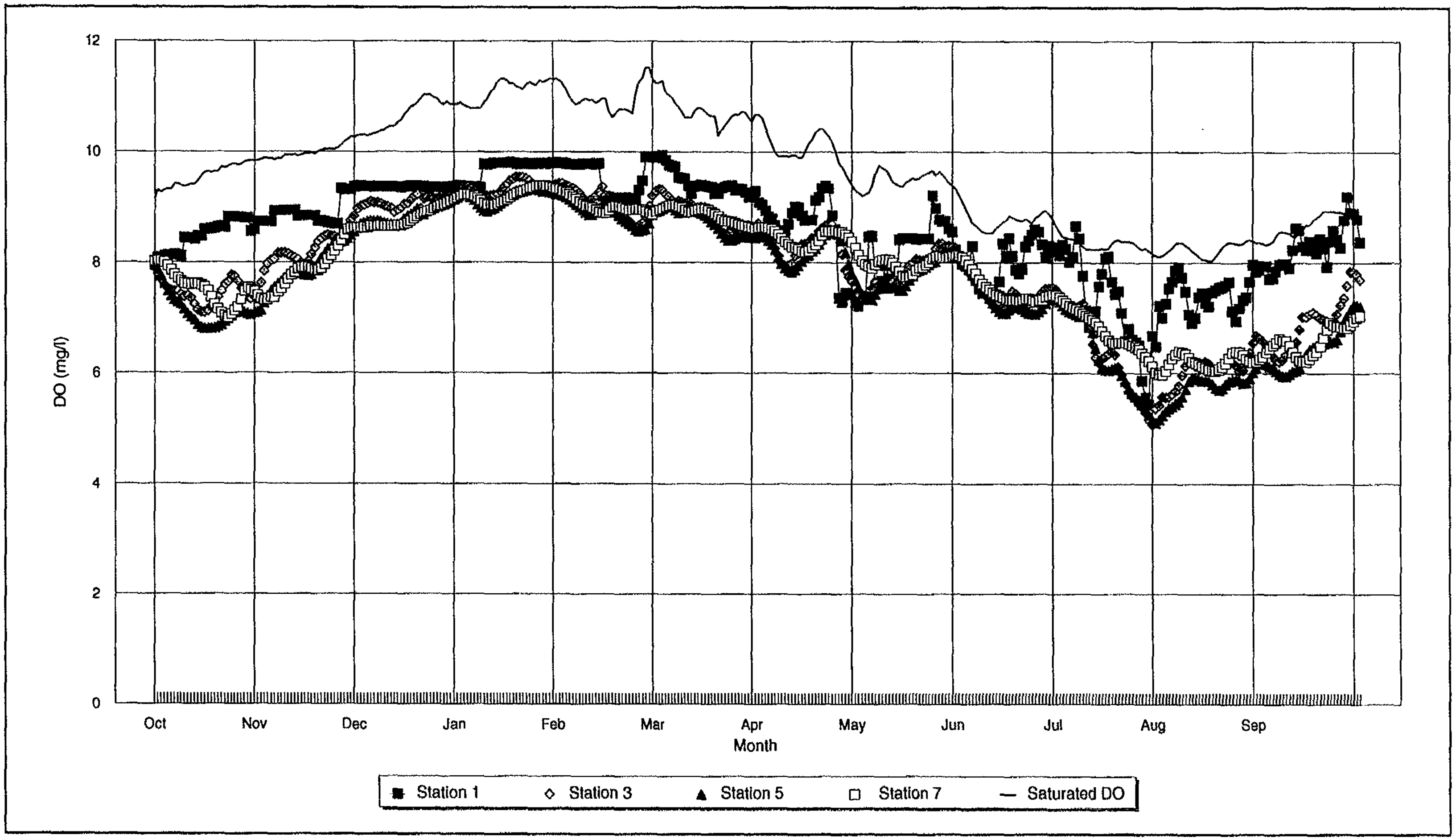
Figure 23
Simulated San Joaquin River Dissolved Oxygen Concentrations for No RWCF Discharge with Net Flow of 1,000 cfs



D-041999

Jones & Stokes Associates, Inc.

Figure 24
Simulated San Joaquin River Dissolved Oxygen Concentrations for 4,500-lbs/day of Oxygen Aeration with Net Flow of 1,000 cfs



Jones & Stokes Associates, Inc.

Figure 25
Simulated San Joaquin River Dissolved Oxygen Concentrations for 50% Sediment Oxygen Demand with Net Flow of 1,000 cfs

D—042000

D-042000